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Effect Of Middle Bridge On Flooding Of The Pettaquamscutt River Narragansett & South Kingstown, Rhode Island

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13. ABSTRACT *(Maximum 200 words)*

This study of the effect of Middle Bridge on flooding of the Pettaquamscutt River was accomplished by the Long Range Planning Branch, Planning Directorate New England Division, U.S. Army Corps of Engineers at the request of the town of Narragansett. The study was funded under the authority provided by the Corps of Engineers' Section 206 Flood Plain Management Services (FPMS) program. Analysis conducted as part of this study shows that the existing Middle Bridge opening has little effect on upstream flood levels or flushing. Under existing conditions, the bridge will cause less than a 0.1 foot difference in water surface elevation from that which exists downstream up to a 10-year event. Events larger than a 10-year event should be even less impacted because of water overtopping the road. Consequently, wider bridge openings will also have minimal effects.

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EFFECT OF MIDDLE BRIDGE ON FLOODING OF PETTAQUAMSCUTT RIVER NARRAGANSETT AND SOUTH KINGSTOWN, RHODE ISLAND

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASSACHUSETTS 02254-9149

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EXECUTIVE SUMMARY

This study evaluated effects of Middle Bridge on flooding in the upper portion of the Pettaquamscutt River in South Kingstown and Narragansett, Rhode Island. Water levels in the river are predominantly controlled by ocean tide levels with minimal influence from freshwater discharges. Analysis conducted as part of this study shows that the existing Middle Bridge opening has little effect on upstream flood levels or flushing. Under existing conditions, the bridge will cause less than a 0.1 foot difference in water surface elevation from that which exists downstream up to a 10-year event. Events larger than a 10-year event should be even less impacted because of water overtopping the road. Consequently, wider bridge openings will also have minimal effects. The only practical means to reduce water quality problems in the upstream ponds involve providing aeration, or mechanically increasing circulation within the ponds, and controlling pollutants either in the watershed or the ponds.

EFFECT OF MIDDLE BRIDGE ON FLOODING OF PETTAQUAMSCUTT RIVER NARRAGANSETT AND SOUTH KINGSTOWN, RHODE ISLAND

HYDRAULIC AND HYDROLOGIC ANALYSIS

TABLE OF CONTENTS

Paragraph	Subject	Page
1	INTRODUCTION	1
2	AUTHORITY	1
3	PROJECT DESCRIPTION	
	a. Location	1
	b. Topography and Morphometry	2
	c. Study Area	3
4	CLIMATOLOGY	
	a. General	3
	b. Temperature and Precipitation	3
	c. Runoff	3
	d. Historic Hurricanes	4
5	SITE HYDROLOGY	
	a. General	4
	b. Freshwater Flow	5
	c. Tidal Regime	5
6	HYDRAULIC ANALYSIS	
	a. Data Collection	8
	b. Computer Model	9
	c. Model Calibration	10
	d. Model Verification	10
	e. Evaluation of Existing Bridge Opening	10
	f. Evaluation of Alternative Bridge Openings	11
	g. Evaluation of Flushing	12
7	SUMMARY	13

LIST OF PLATES

Plate	Description
1	Map of Pettaquamscutt River
2	Pettaquamscutt River Channel Profile
3	Plan View of Middle Bridge
4	Average Annual Flow Rates at Various USGS Gaging Stations
5	Mean Monthly Flow Rates at Various USGS Gaging Stations
6	Tidal Datum Planes, Newport, RI
7A	Tidal Flood Profile - Plan
7B	Tidal Flood Profile - Profile
8	Tidal Datum Planes, Narragansett Pier, RI
9	Gaging Stations Used in the Gaines Study
10	Location of Surveyed Cross Sections
11A	Pettaquamscutt River, Calibration Run, Downstream of Middle Bridge (expanded view)
11B	Pettaquamscutt River, Calibration Run, Downstream of Middle Bridge
12	Pettaquamscutt River, Calibration Run, Upstream of Middle Bridge
13A	Pettaquamscutt River, Verification Run, Downstream of Middle Bridge (expanded view)
13B	Pettaquamscutt River, Verification Run, Downstream of Middle Bridge
14	Pettaquamscutt River Verification Run, Upstream of Middle Bridge
15A	Pettaquamscutt River, Water Surface Elevations, Upstream VS. Downstream of Middle Bridge, April 7, 1993 (expanded view)

LIST OF PLATES (Cont'd)

Plate	Description
15B	Pettaquamscutt River, Water Surface Elevations, Upstream VS. Downstream of Middle Bridge, April 7, 1993
16A	Pettaquamscutt River, Water Surface Elevations, Upstream VS. Downstream of Middle Bridge, 1-Year Event (expanded view)
16B	Pettaquamscutt River, Water Surface Elevations, Upstream VS. Downstream of Middle Bridge, 1-Year Event
17A	Pettaquamscutt River, Water Surface Elevations, Upstream VS. Downstream of Middle Bridge, 10-Year Event (expanded view)
17B	Pettaquamscutt River, Water Surface Elevations, Upstream VS. Downstream of Middle Bridge, 10-Year Event
18	Cross Sections Used For Bridge Analysis
19	Pettaquamscutt River, 10-Year Flood Level, Cross Section 1.841
20	Pettaquamscutt River, 10-Year Flood Level, Cross Section 7
21	Pettaquamscutt River, 10-Year Flood Level, Cross Section 10A
22	Pettaquamscutt River, 10-Year Flood Level, Cross Section 15
23	Pettaquamscutt River, Existing Middle Bridge, April 7, 1993
24	Pettaquamscutt River, Comparison of Water Surface Levels For Three Alternative Bridge Openings, Cross Section 15

EFFECT OF MIDDLE BRIDGE ON FLOODING OF PETTAQUAMSCUTT RIVER NARRAGANSETT AND SOUTH KINGSTOWN, RHODE ISLAND

HYDRAULIC AND HYDROLOGIC ANALYSIS

1. INTRODUCTION

The New England Division Corps of Engineers, was requested by the State of Rhode Island to determine flooding effects of the Pettaquamscutt River in Narragansett and South Kingstown, Rhode Island, from increasing the opening of Middle Bridge. This bridge crosses the Pettaquamscutt River about 1.4 miles upstream from its mouth, linking the towns of South Kingstown and Narragansett, Rhode Island. The bridge is scheduled for reconstruction by the Rhode Island Department of Transportation (DOT) within the next several years.

State and local officials are concerned that the existing Middle Bridge may not allow adequate tidal flushing in upper reaches of the Pettaquamscutt River, exacerbating the present water quality problem in the river. The town of Narragansett requested the DOT investigate alternative design considerations, including widening the bridge opening to induce greater flushing. However, concern was also expressed that increasing the bridge opening size may also increase flooding of shoreline properties upstream from Middle Bridge. This study investigates potential flooding for the existing bridge opening, and two alternative bridge scenarios.

2. AUTHORITY

This study is authorized under the Flood Plain Management Services program in accordance with Section 206 of the Flood Control Act of 1960 (PL 86-645). These regulations provide Federal funds for flood plain management assistance to States and communities.

3. PROJECT DESCRIPTION

a. Location. The project site is located in the towns of South Kingstown and Narragansett (see plate 1), in south-central Rhode Island near the entrance to Narragansett Bay. Middle Bridge spans the Pettaquamscutt River, dividing South Kingstown and Narragansett, and empties into Rhode Island Sound. The bridge is situated approximately 1.4 miles upstream from the river's mouth.

b. Topography and Morphometry. The Pettaquamscutt River begins in North Kingstown, Rhode Island, and runs southerly, bisecting the towns of South Kingstown and Narragansett, to its mouth at the northeast end of Narragansett Beach. The river is a tidal estuary which empties into Rhode Island sound at a point adjacent to the southwest side of Narragansett Bay. Upper reaches are broad and deep, with a natural constriction that creates the appearance of two large ponds (herein referred to as upper and lower ponds). Maximum depths in the ponds are about 65 to 70 feet at mid-tide. The lower reaches are more narrow and shallow, with some areas reaching depths of only a few feet. A broad cove extends southwest of the lower portion of the river downstream from Middle Bridge. This cove is also fairly shallow, being only a few feet deep during normal flow and mid-tide conditions. A profile of the estimated thalweg (line of maximum depth) of the river is shown in plate 2. Elevations are based on USGS mapping, a few surveyed cross sections completed by the Corps in April 1993, and bathymetric mapping received from the University of Rhode Island. The estimated invert ranges from about -4.5 feet NGVD at the mouth to a high point of about -2.0 feet NGVD just downstream from Middle Road Bridge, to approximate elevation -64 feet NGVD in the deepest part of the lower pond.

The upper watershed is marshy near the river, then rises from an elevation of just over 10 feet NGVD to 250 feet NGVD on the western side, and 200 feet NGVD to the east. The mid to lower watershed is narrower. The river is generally narrow with a fairly wide flood plain beyond its banks. The flood plain is generally less than 10 feet NGVD, beyond which the land rises steeply to an elevation of 150 feet NGVD on the west side, and close to 100 feet NGVD on the eastern limits. According to a University of Rhode Island doctoral thesis by Gaines in 1975, the morphometry of the mid to lower reaches of the Pettaquamscutt is continuously modified by estuarine and coastal beach processes, which have created fringing marshes, marsh islands, deltaic features, sandbars, and a spit constricting the river's mouth.

In addition to the Middle Bridge, two other bridges cross over the Pettaquamscutt River, and could influence the flow of water. Bridgetown Bridge (see plate 1) is located about 2.1 miles upstream from Middle Bridge, just below the lower pond. This bridge does not constrict the natural channel, but does obstruct the flood plain. It has one continuous pier through the center of its opening. The other, Governor Sprague Bridge, is located approximately 0.7 mile downstream from Middle Bridge, just past Pettaquamscutt Cove, and situated over a very narrow portion of

the river near its mouth. This bridge does not appear to constrict the natural channel, nor does it cause much obstruction in the flood plain.

c. Study Area. The present configuration of Middle Bridge, at first glance, seems to constrict both the channel and flood plain (see plate 3 for plan view). Channel width during normal flow and tide is about 750 feet upstream, and 650 feet downstream from the bridge, while width of the bridge opening is only 106 feet. Marshy flood plains border the east and west riverbanks, both upstream and downstream of Middle Bridge. Low chord elevation of the bridge opening is 7.5 feet NGVD. Flows begin to bypass the bridge opening at much lower elevations, however, because lowest points in the road embankment are 3.3 and 3.5 feet NGVD on the west and east overbanks, respectively.

The bridge superstructure consists of steel beams and concrete, with concrete and stone abutments. Four rows of one-foot diameter, wooden cylindrical piers are evenly distributed over the width of the opening. Each row consists of a group of eight piers parallel to the direction of flow.

4. CLIMATOLOGY

a. General. The Pettaquamscutt drainage basin has a temperate climate. In winter, coastal storms frequently bring rainfall instead of snow due to the moderating influence of the Atlantic Ocean. In summer, cooling is provided by easterly and southerly sea breezes, thunderstorms from the west, and cool air from the north. Prevailing winds are northwesterly in winter and southwesterly in summer.

b. Temperature and Precipitation. Records are available a few miles west of the basin from the Kingstown, Rhode Island, National Weather Service gage, dating back to 1889. These records are considered representative of the South Kingstown and Narragansett climate. The average annual temperature, based on these gage readings, is 48 degrees Fahrenheit. Annual precipitation ranged from a minimum of 30.7 inches in 1965 to a maximum of 72 inches in 1898. Average annual precipitation at Kingstown is 48 inches.

c. Runoff. Drainage area at the mouth of the Pettaquamscutt River is approximately 13.5 square miles. Average annual runoff in the study area, from U.S. Weather Bureau Hydrologic Atlas No. 57, is about 24 inches (2 csm based on the drainage area).

d. Historic Hurricanes. Some of the heaviest rainfalls recorded were from the dissipating hurricanes "Connie" and "Diane," in August 1955. During 11-15 August, hurricane "Connie" dropped 4 to 6 inches of rain over southern New England. A few days later, hurricane "Diane" produced 16 to 20 inches of rainfall over parts of Massachusetts, with a record 13.1 inches of rainfall in 55 hours at West Mansfield, Massachusetts (40 miles northeast of Narragansett).

On 16-17 September 1932, a tropical storm produced over 12 inches of rainfall in less than 24 hours at Westerly, Rhode Island. Other areas in the State received over 8 inches in 18 hours.

Total rainfall associated with hurricanes, having caused tidal flooding in the Narragansett area, are 2.3 inches in September 1938, 4.0 in September 1944, and 3.0 inches in August 1954 (hurricane "Carol"). The following table lists some of the more severe hurricanes that hit southern New England, and observed rainfall associated with them.

TABLE 1

Storm and Date	Precipitation (inches)	Duration (hours)
"Daisy" - Oct 1962	5.4	57
"Esther" - Sep 1961	7.1	24
"Diane" - Aug 1955	3.1	39
"Connie" - Aug 1955	5.7	29
"Edna" - Sep 1954	5.5	15
"Carol" - Aug 1954	2.9	13
Sep 1944 Hurricane	4.4	52
Sep 1938 Hurricane	2.8	73
Sep 1933 Hurricane	6.0	70

5. SITE HYDROLOGY

a. General. Pettaquamscutt River is a tidal estuary, and water surface levels over its entire length are affected by both freshwater flows and tide levels in Rhode Island Sound. However, due to a small drainage area and direct opening to the ocean, freshwater flows have negligible actual effects on water levels except during major storms. In the 1975 study of the hydrography and geochemistry of the Pettaquamscutt River estuary, Gaines determined that water levels in the river are predominantly controlled by ocean tide levels, with minimal influence from freshwater discharge and other local variables.

b. Freshwater Flow. Drainage area at the mouth of Pettaquamscutt River is about 13.5 square miles. Of this drainage area, almost 10 square miles lie to the north of Middle Bridge, 2.8 square miles drains Pettaquamscutt Cove, and the remaining 0.7 square mile drains the lower portion of the river near its outfall. The upper portion of the river consists of two ponds, identified on plate 1 as the upper and lower ponds. Drainage area at the northernmost portion of the upper pond is about 4.8 square miles. Only flow from about 0.3 square mile enters the far end of the cove. The few tributaries which enter the river's main stem and the cove are extremely small, and most freshwater flow is due to overland runoff.

There are no streamflow records in the Pettaquamscutt River drainage area. A cursory analysis was performed on USGS gaging station records for drainage basins in close proximity with similar hydrologic characteristics. The following table lists drainage areas and average annual flows for Rhode Island gages used in this analysis.

TABLE 2

Gage	Drainage Area (sq. mi.)	Average Annual Flow (cfs)
Hunt River near Greenwich	23.00	46.5
Chipuxet River at W. Kingstown	9.99	21.6
Usquepaug River near Usquepaug	36.10	77.1
Beaver River near Usquepaug	8.87	22.0
Wood River near Arcadia	35.20	77.5

Based on this analysis, a relationship for the Pettaquamscutt basin was developed for average annual and mean monthly flows (see plates 4 and 5). Estimated average annual flow at the mouth of the Pettaquamscutt River is 30 cfs. Mean monthly flows for December, April, and May are 34, 51, and 39 cfs, respectively. These monthly flow rates are mentioned because tide levels were collected at Middle Bridge during December of 1992, and April and May 1993.

c. Tidal Regime. Tides are semidiurnal at the study area, with two high and two low waters occurring each lunar day (approximately 24 hours 50 minutes). The resulting astronomic tide range is constantly varying in response to relative positions of the earth, moon, and sun; the moon having the primary tide-producing effect. Maximum tide

ranges occur when orbital cycles of these bodies are in phase. A complete sequence of tide ranges is approximately repeated over an interval of 19 years, known as a tidal epoch.

The total effect of astronomical tide, combined with storm surge produced by wind, wave, and atmospheric pressure contributions, is reflected in actual tide gage measurements. Since the astronomical tide is so variable at the study area, occurrence time of the storm surge greatly affects the magnitude of the resulting tidal flood level. Obviously, a storm surge on top of a high astronomic tide produces higher water levels than at a lower tide. In addition, the storm surge itself varies with time, thus introducing another variable into makeup of the total flood tide.

The closest National Ocean Survey (NOS) gage is at Newport, RI, located about 10 miles east of the mouth of the Pettaquamscutt River. Tide heights and times have been measured and recorded on a continuous basis at the Newport gage from 1931 to the present. Tidal datum for the Newport gage is shown on plate 6, with mean and mean spring ranges of tides being approximately 3.5 and 4.4 feet, respectively.

NOS also collected tidal data for a short period of time at Narragansett Pier, located about 1 mile south from where the Pettaquamscutt River empties into Narragansett Bay. From these measurements, mean tide and mean spring tide ranges are estimated at 3.25 and 4.0 feet, respectively. Tidal data collected at this pier was also used to establish a correlation with Newport's NOS gage so that long-term historical records at Newport could be used to establish accurate tidal relationships at Narragansett Pier. Since the pier is so close to the mouth of the Pettaquamscutt River, Narragansett Pier's tidal relationship correlation with Newport can approximate conditions at the mouth of the Pettaquamscutt River for this study. In addition, NOS tide gage records at the primary stations of Newport, RI, and New London, CT, have been utilized with coastal high watermark data in development of tidal flood profiles along Narragansett Bay near the mouth of the Pettaquamscutt River. These profiles, for the open ocean in the Narragansett area, are shown on plates 7A and 7B. Information on Narragansett Pier tidal datum is presented in plate 8 and in table 3.

The tidal regime was initially estimated throughout the Pettaquamscutt River estuary by Gaines (1975), who collected tide data from three different gaging stations along the Pettaquamscutt River between December 1969 and September 1970. The first station is located at the northern end of

TABLE 3

ESTIMATED
TIDAL DATUM PLANES
NARRAGANSETT PIER

(Estimated from correlation with the Newport, Rhode Island National Ocean Service tide gage data and Corps of Engineers Tidal Flood Profiles, New England Coastline, dated September 1988)

	Tide Level (feet NGVD)
100-Year Frequency Flood Event	13.9
September 1938 Hurricane	13.8
Hurricane "Carol" - 1954	12.8
50-year Frequency Flood Event	12.1
10-year Frequency Flood Event	8.3
11 December 1992 Storm	4.6
1-Year Frequency Flood Event	4.2
Mean Spring High Water (MHWS)	2.3
Mean High Water (MHW)	2.0
Mean Tide Level (MTL)	0.3
National Geodetic Vertical Datum	0.0
Mean Low Water (MLW)	-1.3
Mean Lower Low Water (MLLW)	-1.4
Mean Spring Low Water (MLWS)	-1.7

upper pond, the second is near Bridgetown Road Bridge, and the third is near Governor Sprague Bridge (see plate 9). During this study, he observed the following changes in tidal wave recording at the Newport gage with respect to distance up the estuary: "(1) a decrease in tidal range, (2) a progressive lag in the times of high and low water, (3) a steepening of the wave front, i.e., a decrease in the duration of rise and an increase in the duration of fall, and (4) a rounding off of the wave crest." For the period of record of Gaines' study (1969-1970), mean tide ranges at stations 1, 2, and 3 are 0.35, 0.41, and 1.47 feet, respectively (mean tide range at Newport was 3.53 feet).

6. HYDRAULIC ANALYSIS

a. Data Collection. Topographic and tidal monitoring data at the site were collected to describe the existing tidal regime, and obtain information to calibrate and verify a one dimensional tidal flow model. A survey of several cross sections along the river, shown in plate 10, was completed in April 1993 to provide adequate information on the topography. This was necessary since the only available mapping was in the Narragansett Pier and Wickford, RI, U.S. Geological Service quadrangles, and bathymetric maps of the upper and lower ponds, obtained from the University of Rhode Island.

In addition, the geometric configuration of Middle Bridge is a critical element and the following information was procured. Low chord and bridge deck elevations at the bridge and channel centerline are 7.5 and 9.9 feet NGVD, respectively. The roadway elevation falls off on each side from the center of the bridge to a low of 3.3 feet NGVD on the west bank, and 3.5 feet NGVD on the east bank before slowly rising. This means that when river stages are higher than 3.3 feet NGVD, flow begins to circumvent the bridge. Therefore, the bridge may have an effect during low to moderate storm surge events before the water surface level begins to overtop the road. During high surge events, however, flow would be less restricted by the bridge structure and would pass around the structure. It is estimated that water surface levels become more nearly equal upstream and downstream of the bridge, the more severe the storm event.

For tidal monitoring purposes, two staff gages were installed in the Pettaquamscutt River, one about 50 feet upstream of Middle Bridge, and the other about 50 feet downstream of the bridge. Tidal data collected were referenced to National Geodetic Vertical Datum (NGVD) to allow correlation with data established for Narragansett

Pier. The correlation allows NED to estimate historic tide levels in the Pettaquamscutt River, based on historic data collected at the primary NOS gage at Newport and its established correlation with Narragansett Pier. These relationships are the basis for any predictive analysis completed on the Pettaquamscutt River. The intent of data collection was to document the movement of tides through the bridge, and provide calibration data for a numerical model developed to analyze resultant tidal conditions for various size bridge openings.

Tidal data were collected at the two gages for two different partial tide cycles during 7 April and 6 May 1993. In addition, tidal data were collected from the NOS tide gage at Newport for the same days. These tidal events were considered to be higher than a mean spring tide range condition since high tide levels at the Newport gage reached 3.1 and 2.8 feet NGVD on 6 April and 7 May, respectively. Mean high spring tide level at Newport is about 2.7 feet NGVD. Estimated high tide elevations for Narragansett Pier at the mouth of the Pettaquamscutt River, based on correlation with Newport, were 2.7 and 2.4 feet NGVD, respectively. Mean spring tide at Narragansett Pier is about 2.3 feet NGVD. The high tide level for 6 April was 2.15 feet NGVD for the downstream gage, and 2.10 feet NGVD for the upstream gage. On 7 May, tide levels reached 1.85 feet NGVD on the downstream side, with the same level reached on the upstream side. In general, for the days studied, data showed that the existing bridge opening provides only minimal restrictions for flows from a mean spring tide range. The maximum water surface elevation difference, measured between the upstream and downstream gages, was 0.15 foot at any one instant in time.

b. Computer Model. A one-dimensional hydrodynamic model, UNET, was selected for analysis of Middle Bridge since it is the latest, most advanced model readily available, providing reasonable results without difficulties associated with a 2-dimensional model. This hydrologic model became available for Corps use in September 1992, and later updated in March 1993.

UNET, using the properties of continuity and momentum, applies a linearized, implicit, finite-difference scheme to solve a set of linear equations. The equations are linearized, using the first-order Taylor approximation. The program can simulate one-dimensional unsteady flow through a full network of open channels. For subcritical flow, stages are a function of channel geometry, and downstream backwater effects. UNET provides the user with the ability to apply several external and internal boundary conditions, including

flow and stage hydrographs, bridges, spillways, levee systems and culverts. Cross sections are input in a modified HEC-2 forewater format. The model uses Mannings "n" values to approximate the natural friction values of the channel.

c. Model Calibration. Water surface elevations upstream and downstream of middle bridge, measured on 7 April 1993, were used to calibrate the UNET model.

Results of the calibrated run for 7 April are shown on plates 11A, 11B, and 12. Computed results match observed data very closely; the timing and elevations of high tide levels match almost exactly, and computed low tide levels are only 0.1 to 0.2 foot higher than observed. The "n" values used for the river channel for this study varied from 0.02 to 0.04.

d. Model Verification. After calibrating the model using the 7 April 1993 data, the model was run again for the other measured event--6 May 1993. Verification results are shown in plates 13A, 13B, and 14. The high tide levels matched within 0.05 foot with only minor differences in timing, and the low tide levels were within 0.2 foot. The model was considered to be calibrated and verified to the degree needed for accurate predictive results.

e. Evaluation of Existing Bridge Opening. The major purpose of the modelling was to investigate the extent to which the existing bridge (106 feet wide) reduces flood stages and impacts flushing characteristics.

As already shown in actual measured tidal measurements, the existing bridge causes minimal changes in river water surface elevations. Simulations of the bridge under approximate high spring tide (7 April 1993 event), estimated 1-year, and estimated 10-year storm tide conditions are shown in water surface elevations presented in cross sections upstream and downstream of the bridge in figures 15A through 17B. The maximum water surface elevation difference between upstream and downstream cross sections for the estimated spring tide range (7 April 1993 event) at high tide is 0.04 foot.

The 1-year event was selected since the water surface elevation at Middle Bridge is approximately the highest that can be reached without overtopping the causeway road (elevation 3.3 feet NGVD) which leads up to the bridge. The 1-year event produces an elevation of approximately 4.6 feet NGVD at Narragansett Pier and 4.2 at the bridge. The maximum computed difference in water surface elevation between upstream versus downstream cross sections was approximately 0.05 foot.

The estimated 10-year storm tide condition was the maximum storm event selected for analysis. The tide level (approximately 8.3 feet NGVD at Narragansett Pier and 7.9 at the bridge) associated with this storm is significantly higher than top of the causeway road leading up to Middle Bridge. The difference in water surface levels between upstream versus downstream cross sections for this event is estimated to be 0.08 foot. Storm events, having significantly higher water levels than the road, will have less impact on water surface elevations because flow through the bridge is much less than that over the causeway.

A sensitivity analysis was performed for Manning's "n" value for the bridge because it can be a critical element in the predictive analysis. The Mannings "n" value chosen for modelling the bridge cross sections was 0.045, and the sensitivity analysis evaluated "n" values of 0.03 and 0.06 for an estimated 1-year event. The variation in water surface elevations for the different "n" values was found to be less than 0.01 foot. This showed that the exact value of "n" was not critical as long as it was taken from the range of reasonable values.

f. Evaluation of Alternative Bridge Openings. Two alternative bridge opening scenarios (159 and 212 feet wide) were evaluated for differences from the existing conditions.

Computer simulations of the two other bridge opening scenarios were conducted; upstream and downstream water surface elevations from the Middle Bridge were compared to the existing bridge opening simulation. The scenarios were evaluated during high spring tide, estimated one-year and estimated 10-year storm events. River stages just downstream of the Middle Bridge for these events were approximately 2.1, 4.2, and 7.9 feet NGVD, respectively. It was not necessary to evaluate more severe storms since significant overtopping of the causeway road already occurs during the 10-year event.

Four cross sections upstream of the bridge were selected for use in comparing water surface elevation differences, based on wider bridge openings at Middle Bridge. The cross section locations are shown in plate 18. Section 15 is located at the upper end of Pettaquamscutt River where it enters Carr Pond, 10a is 525 feet downstream of Bridgetown Road bridge, section 7 is one mile upstream of Middle Bridge, and 1.841 is 100 feet upstream of Middle Bridge. These sections were evaluated because they are located near heavily populated areas upstream of Middle Bridge. Plates 19 through 22 show a portion of computer simulation results (the 10-year

event) at four cross sections for the existing condition, and the two alternative bridge openings.

Under spring tide conditions, maximum water surface elevation differences from the three bridge scenarios were less than 0.05 foot at all four stations. Under estimated 1 and 10-year storm conditions, maximum water surface elevation differences between existing and larger bridges were less than 0.1 foot.

A cursory analysis was also conducted to see what would happen with a smaller bridge opening (53-foot wide span). For a spring tide event, the additional constriction lowered the water surface elevation for the cross section immediately above the bridge, 0.1 foot below that estimated for the existing bridge condition.

g. Evaluation of Flushing. Water surface plots for an estimated full tide cycle for the 7 April 1993 event, at the cross sections immediately downstream and upstream of the bridge and at the northern end of the upper pond, are shown in plate 23. The tide range at the upper end of the Pettaquamscutt is approximately 0.7 foot, and the tide range just above the bridge about 1.5 feet. An estimate of the tidal volume interchange above the bridge, based on the average tide range above the Middle Bridge for the 7 April 1993 event, is approximately 400 acre-feet. Based on this volume, average flow rate for the estuary at the bridge over a 6-hour tide cycle is approximately 800 cfs. From the model, peak ebb and floodflow conditions are estimated at 1,450 and 620 cfs, respectively. Regardless of which tidal flow estimate is used for comparison, it is a significant change from the average annual freshwater flow rate of 30 cfs. Tidal flows clearly dominate river hydraulics.

From bathymetric mapping supplied from URI, the volume of water below mean spring low water for the upper and lower ponds alone is about 4,600 acre-feet. There is also approximately 500 acre-feet of water below mean spring low water in the portion of river between Middle Bridge and the lower pond. Therefore, compared to the estimated 400 acre-feet exchanged during the estimated spring tide range event, each tidal cycle will flush only about 7 percent of the total volume of water above the bridge under existing conditions. Depth of the ponds and lack of flushing allow water quality problems to develop in the upper area of the Pettaquamscutt. Pollutants and the natural buildup of organic matter in deeper parts of the ponds result in anoxic conditions with all the associated problems. Water quality problems will not be as severe in the river downstream of the ponds since the

shallow depth and existing tidal flushing characteristics would result in a generally aerobic condition.

Plate 24 compares tide cycles at the upper end of the pond, during the estimated 7 April 1993 event, for existing conditions and the two alternative openings. Differences between existing conditions and the alternatives at high and low tide are, at the most, 0.1 foot. Since widening the bridge opening to 212 feet, results only in a difference of less than 0.1 foot, the change in flushing and resultant improvement in water quality will be immeasurable. Flushing would be improved if the channel above, through, and below the bridge were deepened. However, the lowest practical invert would be mean low tide level (-1.3 feet NGVD), which would not significantly change the volume interchanged. The most practical means to improve water quality in the ponds would be to eliminate pollutant sources in the upstream watershed, provide aeration within the ponds, or increase the circulation within the ponds through pumping or mechanical mixing.

7. SUMMARY

This study evaluated effects of Middle Bridge on flooding in the upper portion of the Pettaquamscutt River in South Kingstown and Narragansett, Rhode Island. This analysis shows that the existing Middle Bridge opening has little effect on upstream flood levels or flushing. Consequently, wider bridge openings will also have minimal effects. The only practical means of reducing water quality problems in up-stream ponds involves providing aeration or mechanically increasing circulation within the ponds, and controlling pollutants either in the watershed or the ponds themselves.

Middle Bridge crosses the Pettaquamscutt River about 1.4 miles upstream from its mouth, linking the towns of South Kingstown and Narragansett. The bridge is scheduled to be reconstructed by the Rhode Island Department of Transportation within the next several years.

Water levels in the river are predominantly controlled by ocean tide levels with minimal influence from freshwater discharges. The estimated average annual flow at the mouth is 30 cfs, while an estimated spring tide range average flow rate, over a 6-hour period for ebb or flood conditions near the bridge, is estimated to be 800 cfs or approximately 25 times the freshwater flow rate.

At the site, tidal monitoring data were collected to describe the existing tidal regime. From tidal measurements,

the existing bridge causes minimal changes upstream in water surface elevations from that existing downstream of the bridge.

A one-dimensional hydrodynamic model, UNET, was selected to provide a predictive analysis of various flow conditions for the existing Middle Bridge as well as providing analysis of larger sized openings for the Middle Bridge. Under existing conditions, the model shows that the bridge will cause less than a 0.1 foot difference in water surface elevation from that existing downstream up to a 10-year event (water surface elevation at the bridge equal to 7.9 feet NGVD). Events greater than 10-years should be less impacted by the opening, since water overtops the road when water levels are greater than approximately 3.3 feet NGVD.

For existing bridge opening (106 feet wide) as well as the two alternative openings (159 and 212 feet wide), the maximum water surface elevation difference for a spring tide condition was less than 0.05 foot for locations upstream of the bridge. Under estimated 1 and 10-year storm conditions, the maximum water surface elevation difference between existing and larger bridges was less than 0.1 feet.

Under existing conditions, an estimate of the tidal volume interchange above the bridge, based on the tide range at the upper end of the Pettaquamscutt for the 7 April 1993 event, is approximately 400 acre-feet. Based on available bathymetric mapping of the upper end of the Pettaquamscutt, this interchange volume is only about 7 percent of the total volume of water existing above the bridge under estimated existing conditions. A majority of the water is below the low tide condition of the upper river, and normal flushing action of the tides will have no impact on this deeper portion. Depth of the ponds and lack of flushing allow water quality problems to develop. Pollutants and the natural buildup of organic matter in deeper parts of the ponds result in anoxic conditions with all the associated problems.

Widening the opening of the bridge to 212 feet, would result in a difference of less than 0.1 foot, and the change in flushing and improvement in water quality from existing conditions will be nearly immeasurable.

PETTAQUAMSCUTT RIVER

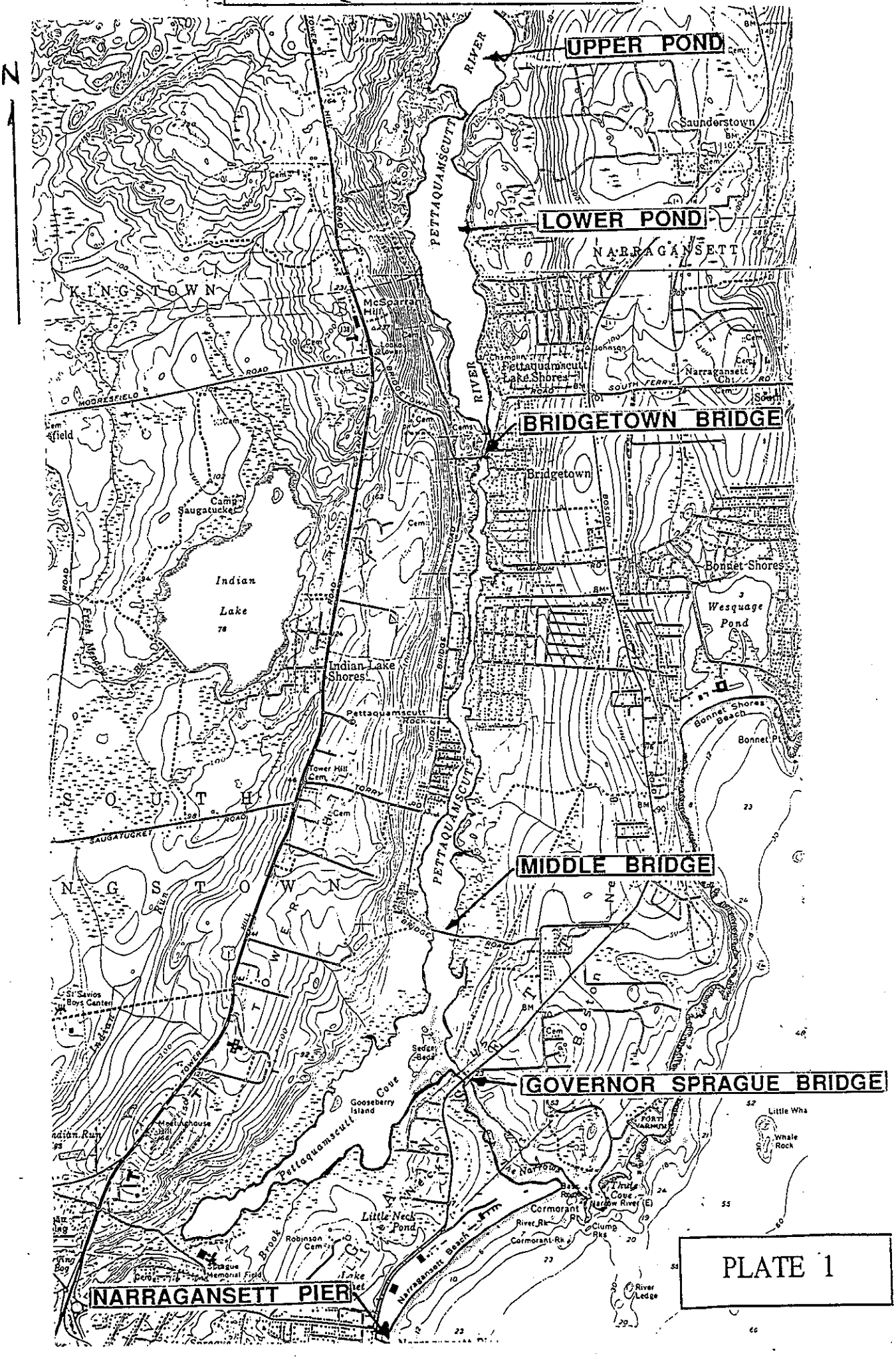


PLATE 1

PETTAQUAMSCUTT RIVER
CHANNEL PROFILE

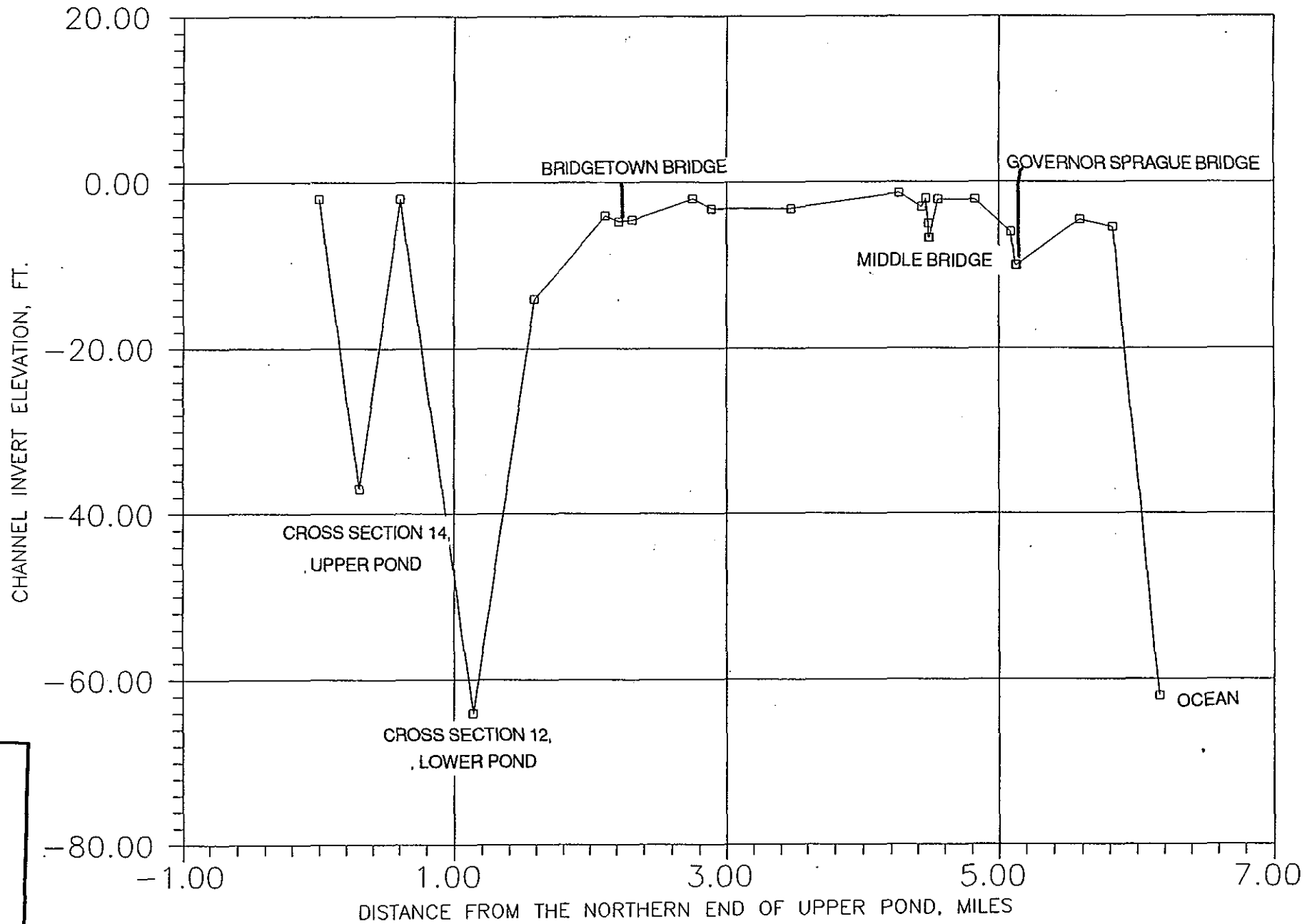


PLATE 2

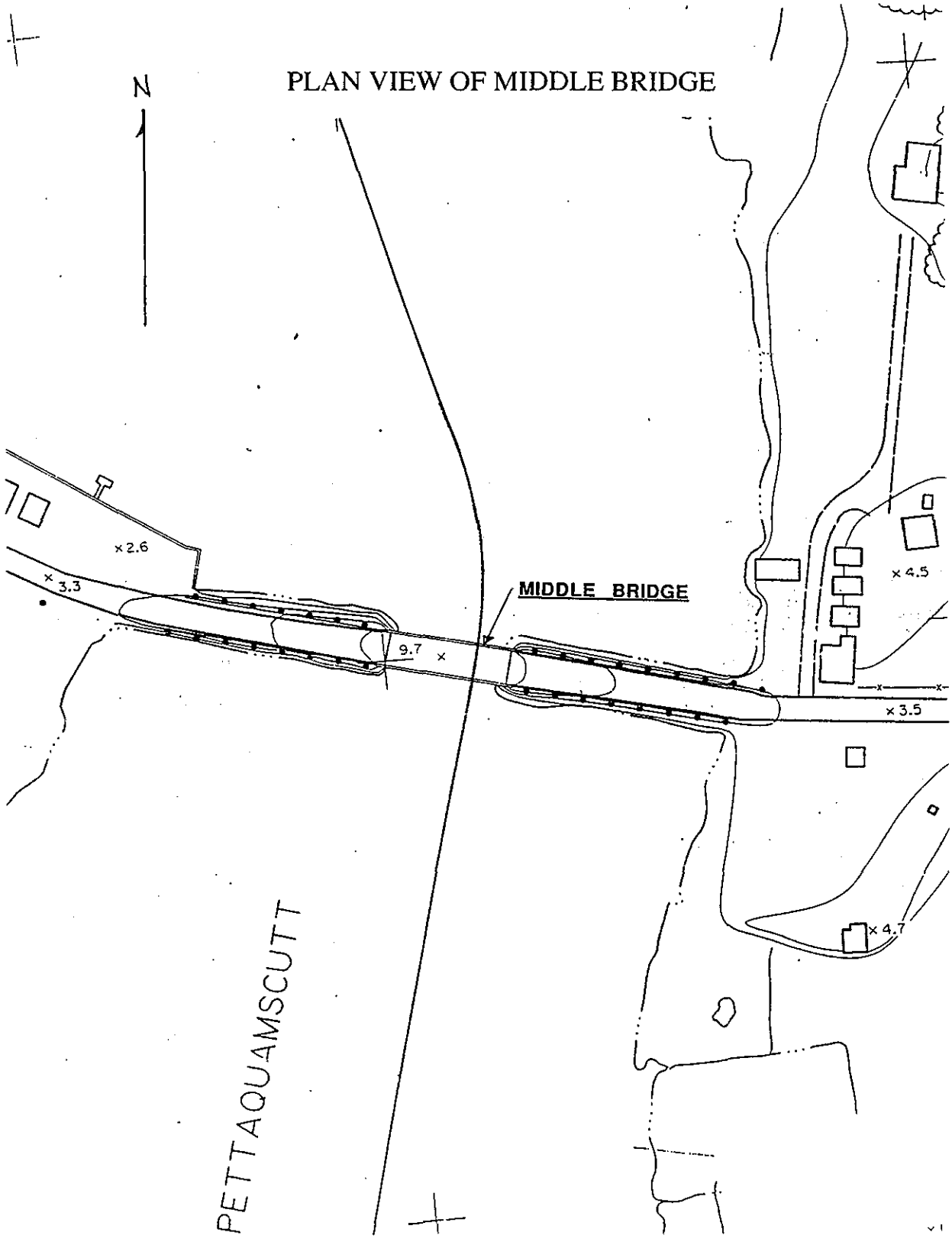
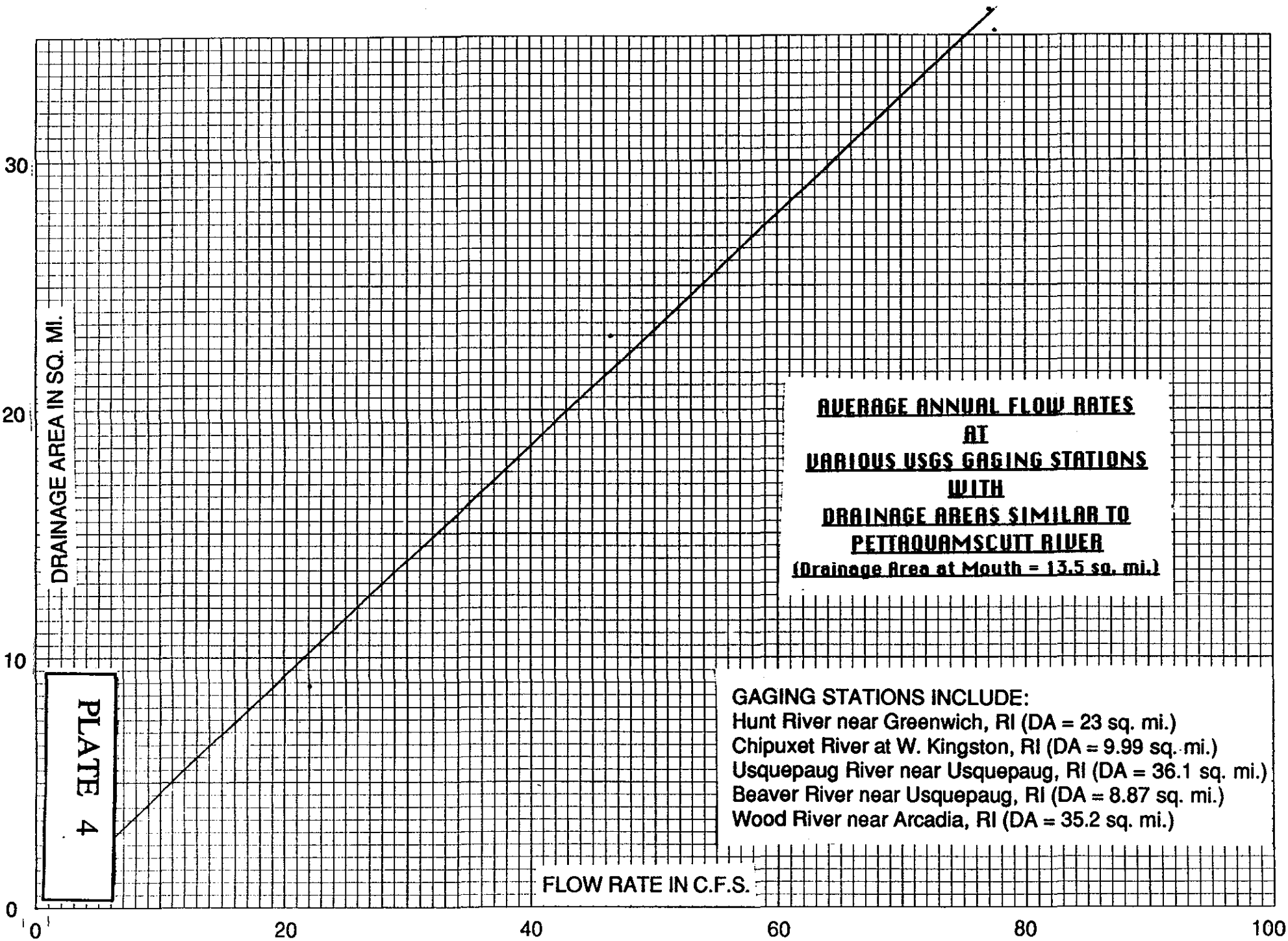
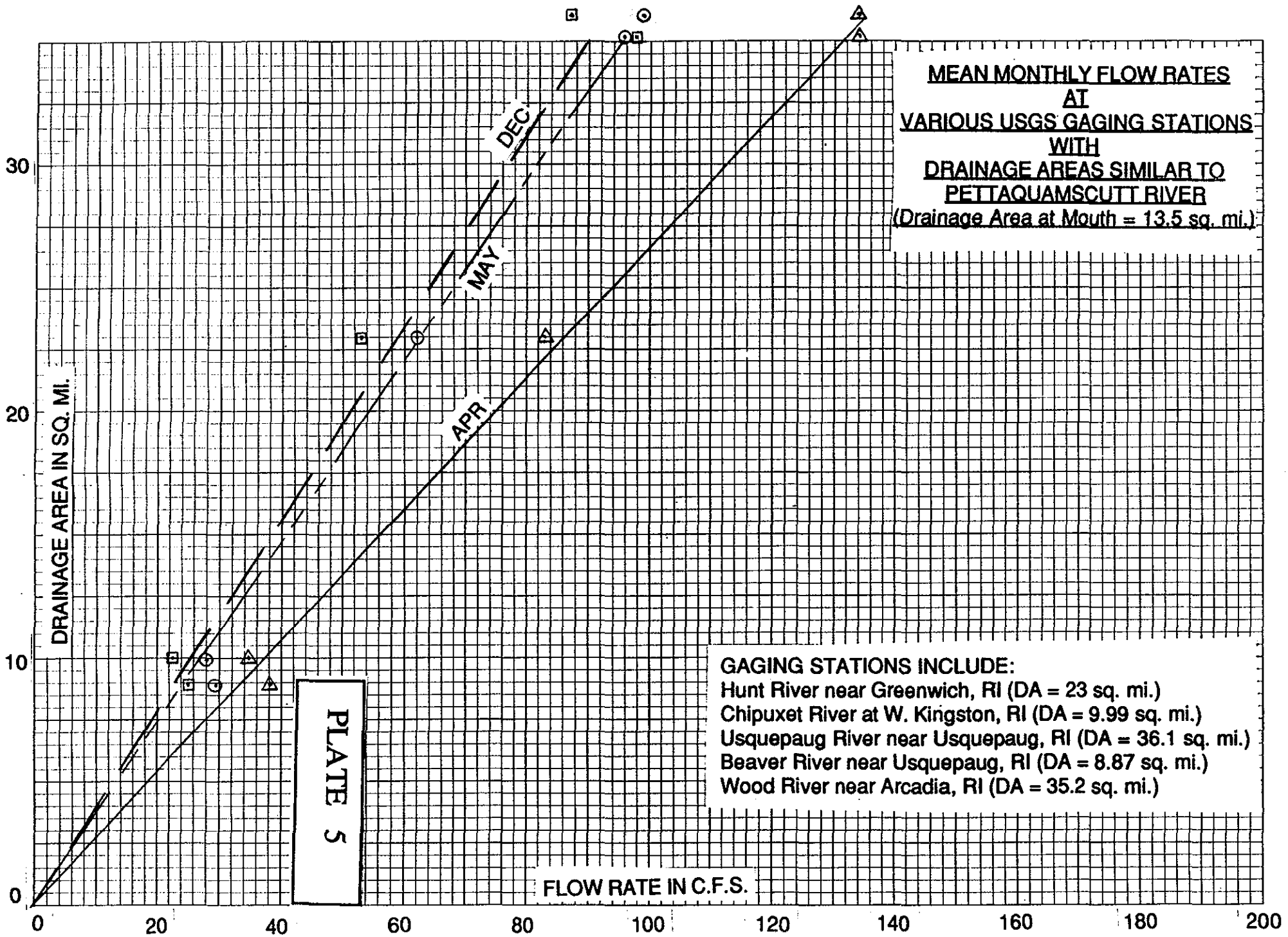

PLAN VIEW OF MIDDLE BRIDGE
N
MIDDLE BRIDGE
×2.6
×3.3
9.7
×4.5
×3.5
×4.7
PETTAQUAMSCUTT

PLATE 3

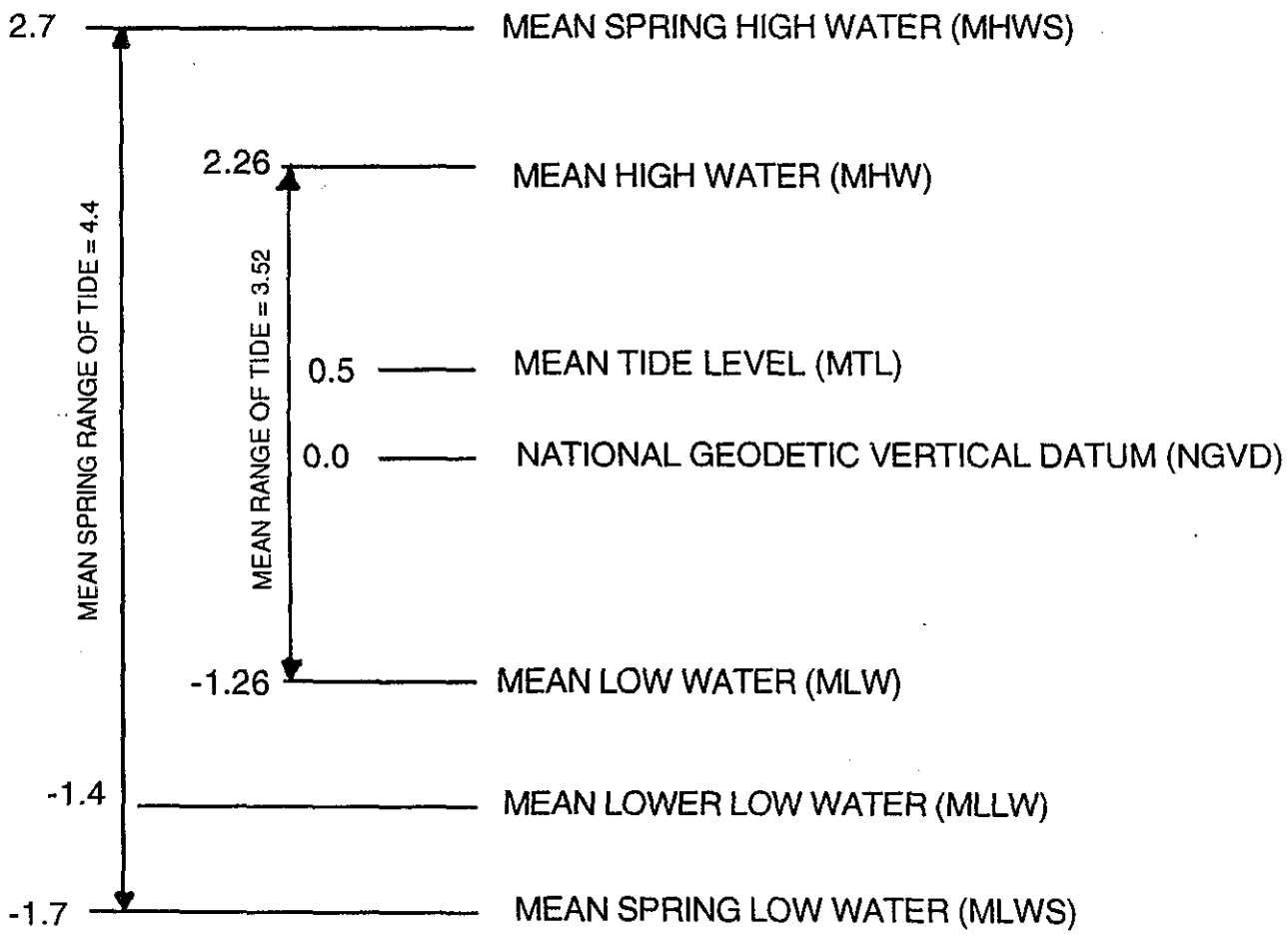
K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



K&E 5 X 5 TO 1/2 INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.



TIDAL DATUM PLANES
NEWPORT, RHODE ISLAND
NATIONAL OCEAN SURVEY TIDE GAGE
(BASED UPON 1960 - 78 TIDAL EPOCH)



NEW ENGLAND DIVISION
U.S. ARMY, CORPS OF ENGINEERS
WALTHAM, MASS. SEPT. 1993

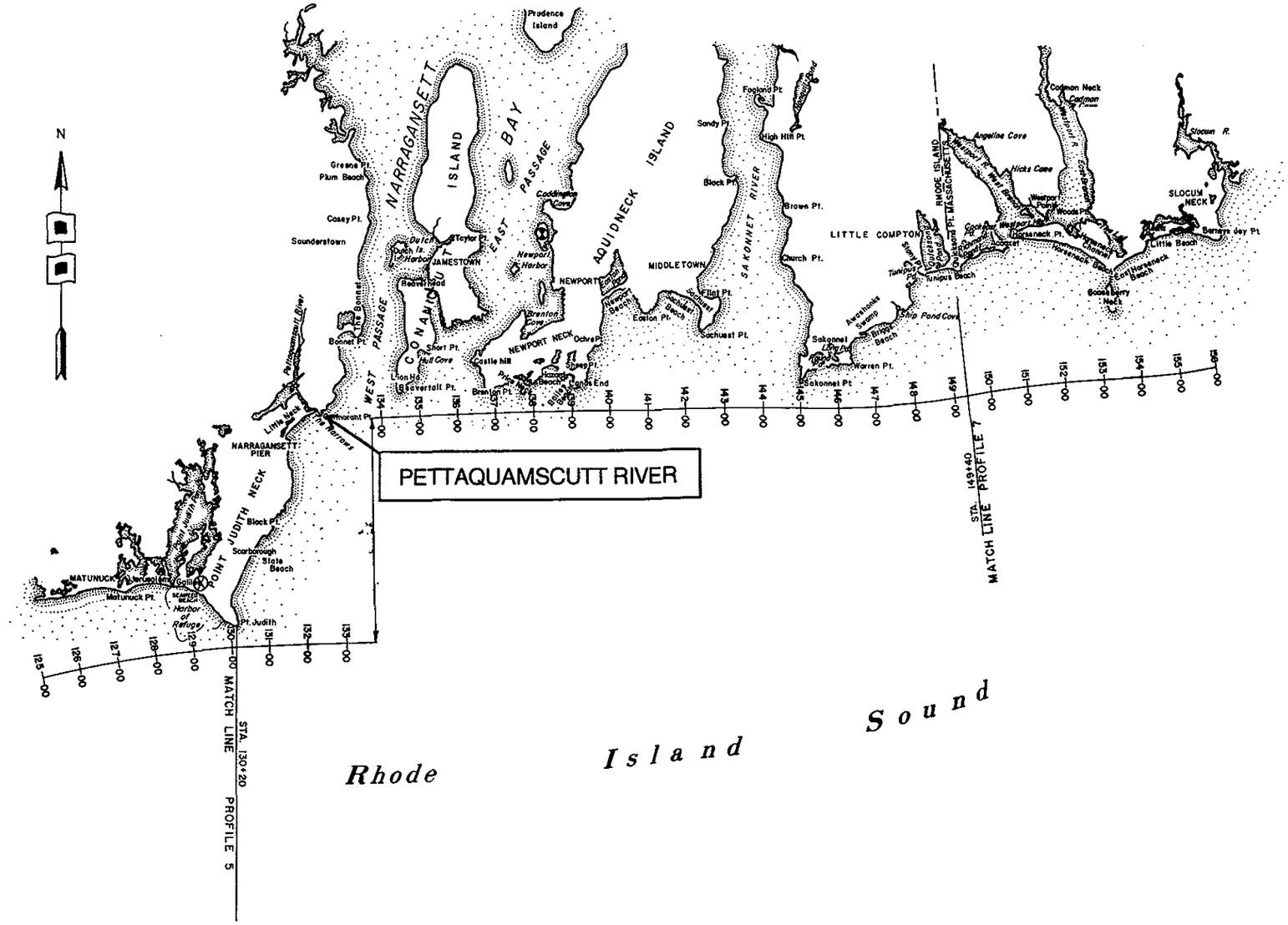
PLATE 6

CORPS OF ENGINEERS

U. S. ARMY

R H O D E I S L A N D

MASSACHUSETTS



LEGEND

⊗ NED Gage

⊗ National Ocean Survey Gage

PLATE 7A

NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY

BASE MAP FOR PROFILE NO. 6

NARRAGANSETT, R.I., TO
LITTLE COMPTON, R.I.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1988

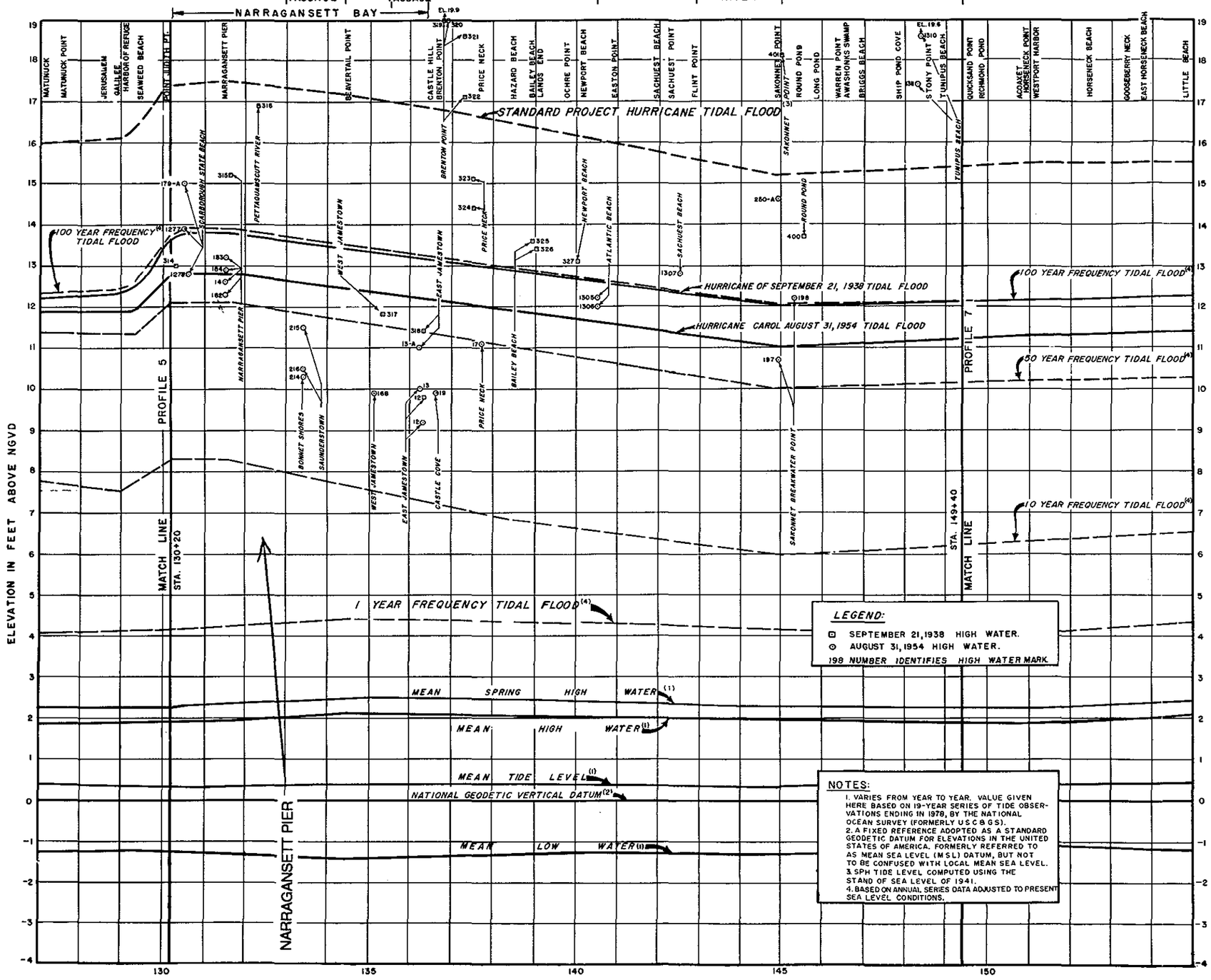
CORPS OF ENGINEERS

U. S. ARMY

RHODE ISLAND — MASSACHUSETTS

NARRAGANSETT | WEST PASSAGE | JAMESTOWN | EAST PASSAGE | NEWPORT | MIDDLETOWN | SAKONNET RIVER | LITTLE COMPTON

NARRAGANSETT BAY



LEGEND:

- ⊡ SEPTEMBER 21, 1938 HIGH WATER.
- ⊙ AUGUST 31, 1954 HIGH WATER.
- 198 NUMBER IDENTIFIES HIGH WATER MARK.

NOTES:

1. VARIES FROM YEAR TO YEAR. VALUE GIVEN HERE BASED ON 19-YEAR SERIES OF TIDE OBSERVATIONS ENDING IN 1978, BY THE NATIONAL OCEAN SURVEY (FORMERLY U.S.C.&G.S.).
2. A FIXED REFERENCE ADOPTED AS A STANDARD GEODETIC DATUM FOR ELEVATIONS IN THE UNITED STATES OF AMERICA. FORMERLY REFERRED TO AS MEAN SEA LEVEL (M.S.L.) DATUM, BUT NOT TO BE CONFUSED WITH LOCAL MEAN SEA LEVEL.
3. SPH TIDE LEVEL COMPUTED USING THE STAND OF SEA LEVEL OF 1941.
4. BASED ON ANNUAL SERIES DATA ADJUSTED TO PRESENT SEA LEVEL CONDITIONS.

PLATE 7B

NEW ENGLAND COASTLINE
TIDAL FLOOD SURVEY

TIDAL FLOOD PROFILE NO. 6

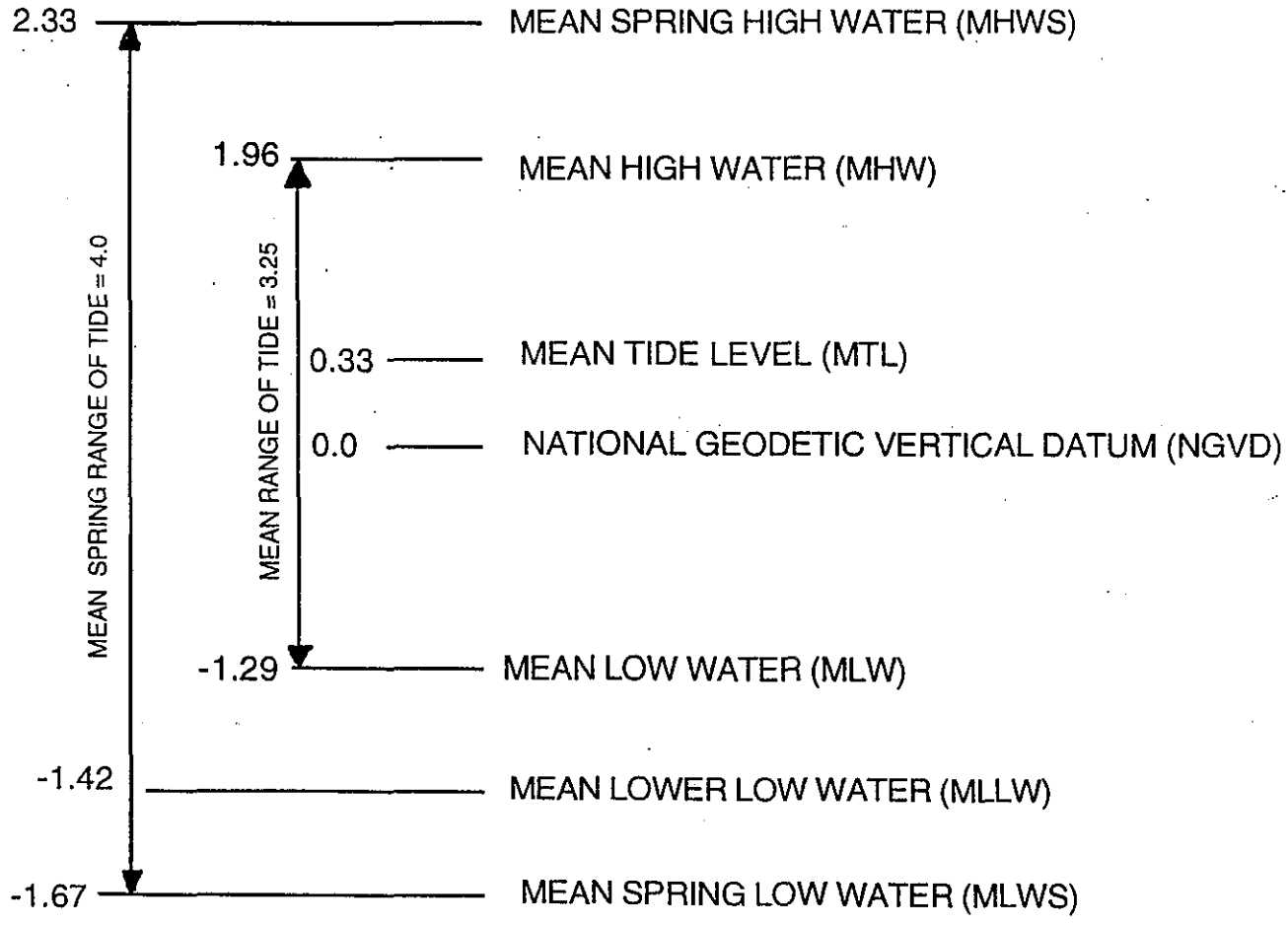
NARRAGANSETT, R.I. TO
LITTLE COMPTON, R.I.

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
WALTHAM, MASS.
SEPTEMBER 1988

TIDAL DATUM PLANES
NARRAGANSETT PIER, RHODE ISLAND
NATIONAL OCEAN SURVEY TIDE GAGE

(BASED UPON 1960 - 78 TIDAL EPOCH)

(BASED ON CORRELATION WITH PRIMARY NOS GAGE AT NEWPORT, RI)



NEW ENGLAND DIVISION
U.S. ARMY, CORPS OF ENGINEERS
WALTHAM, MASS. SEPT. 1993

PLATE 8

GAGING STATIONS USED IN THE GAINES STUDY

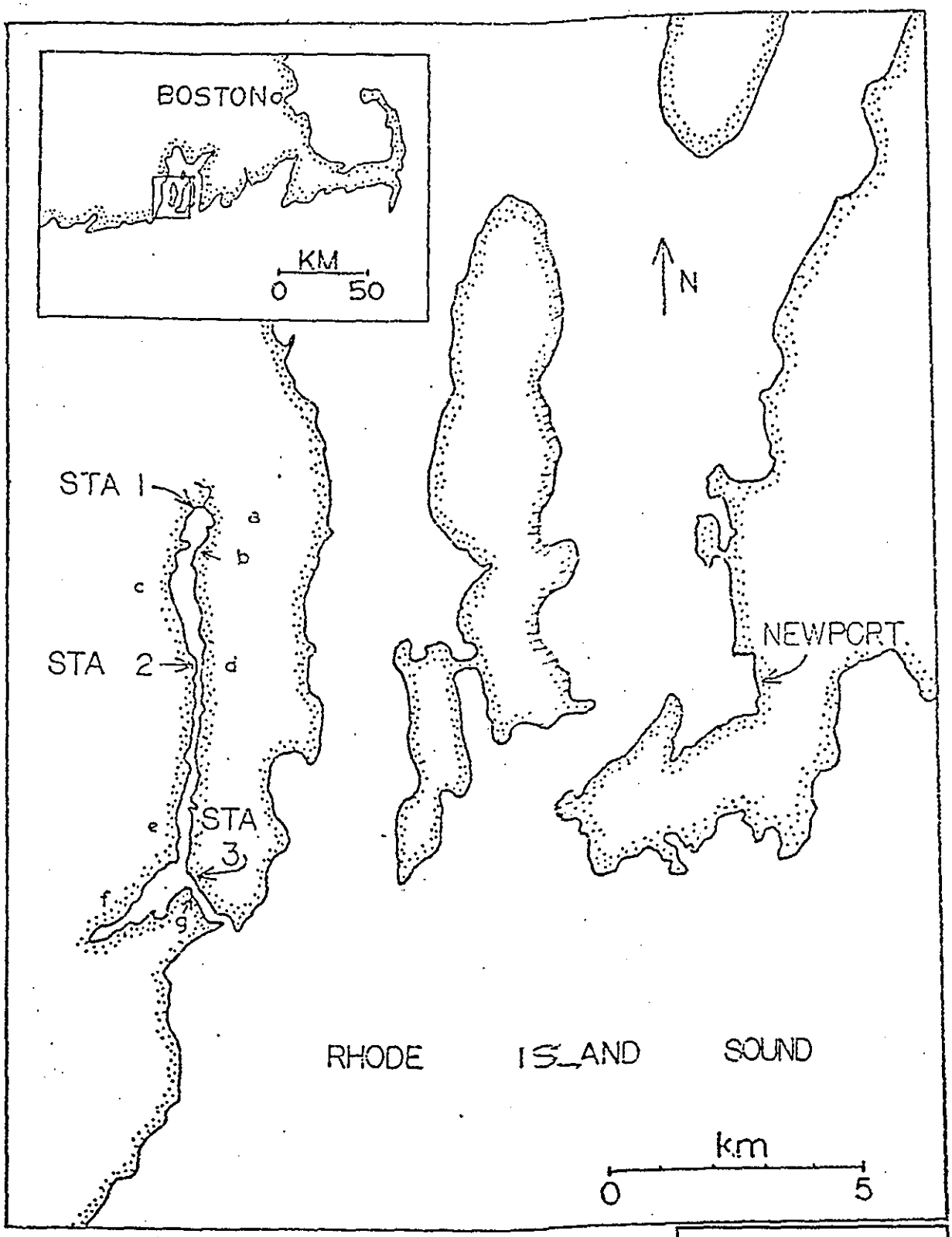


PLATE 9

LOCATION OF SURVEYED CROSS SECTIONS

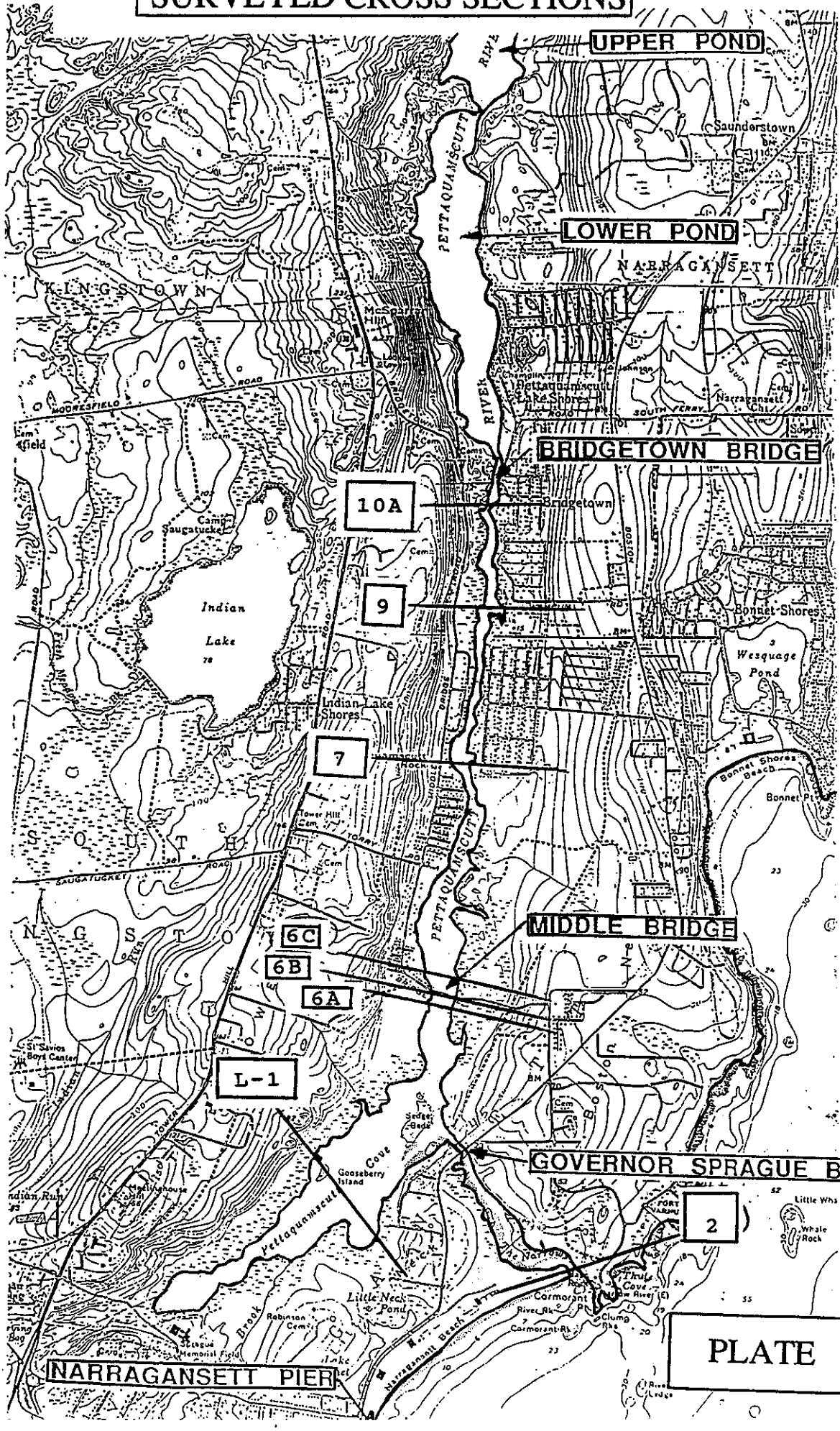


PLATE 10

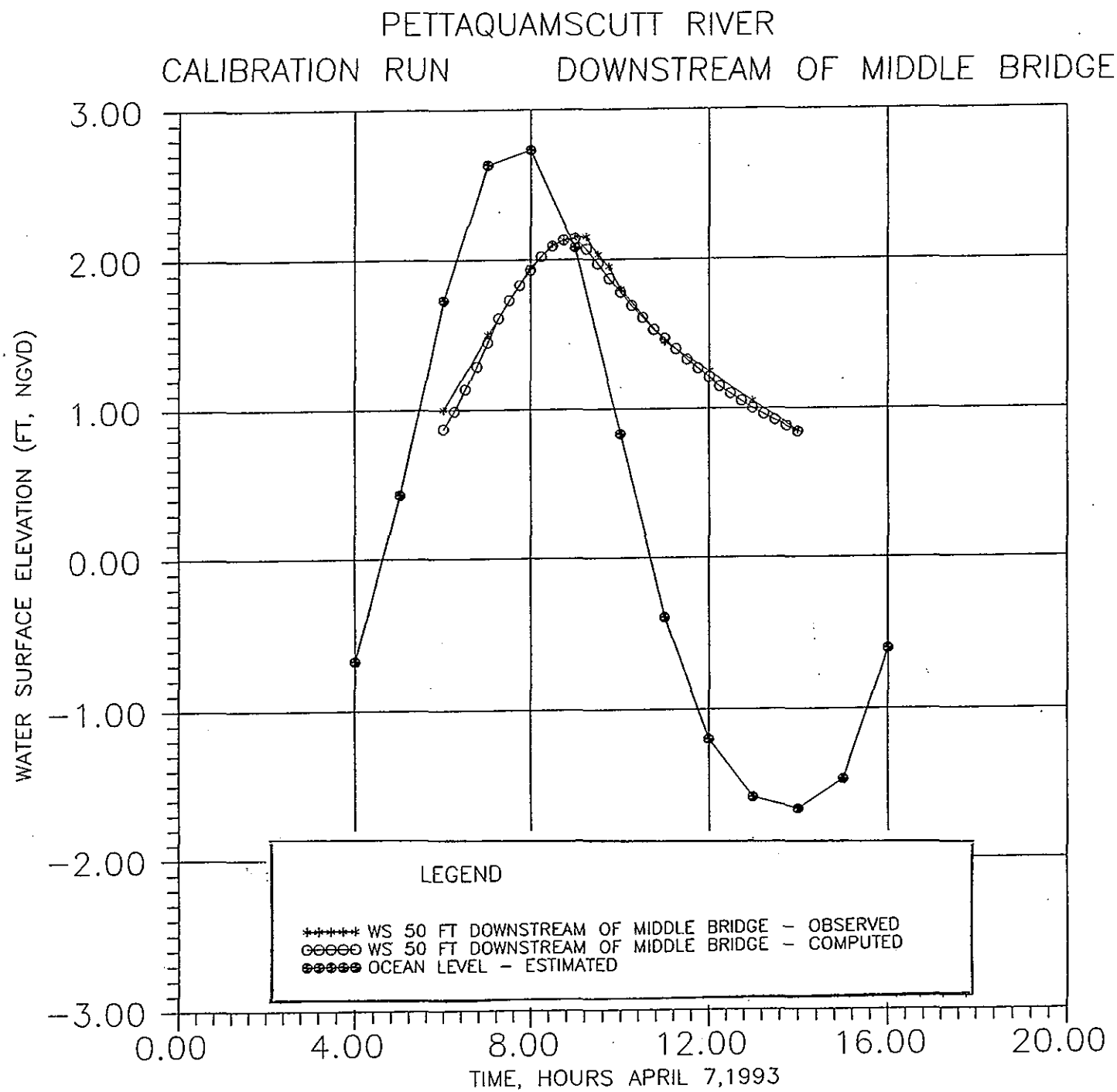

PETTAQUAMSCUTT RIVER
CALIBRATION RUN DOWNSTREAM OF MIDDLE BRIDGE
WATER SURFACE ELEVATION (FT, NGVD)
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
0.00
4.00
8.00
12.00
16.00
20.00
TIME, HOURS APRIL 7,1993
LEGEND
WS 50 FT DOWNSTREAM OF MIDDLE BRIDGE - OBSERVED
WS 50 FT DOWNSTREAM OF MIDDLE BRIDGE - COMPUTED
OCEAN LEVEL - ESTIMATED

PLATE 11A

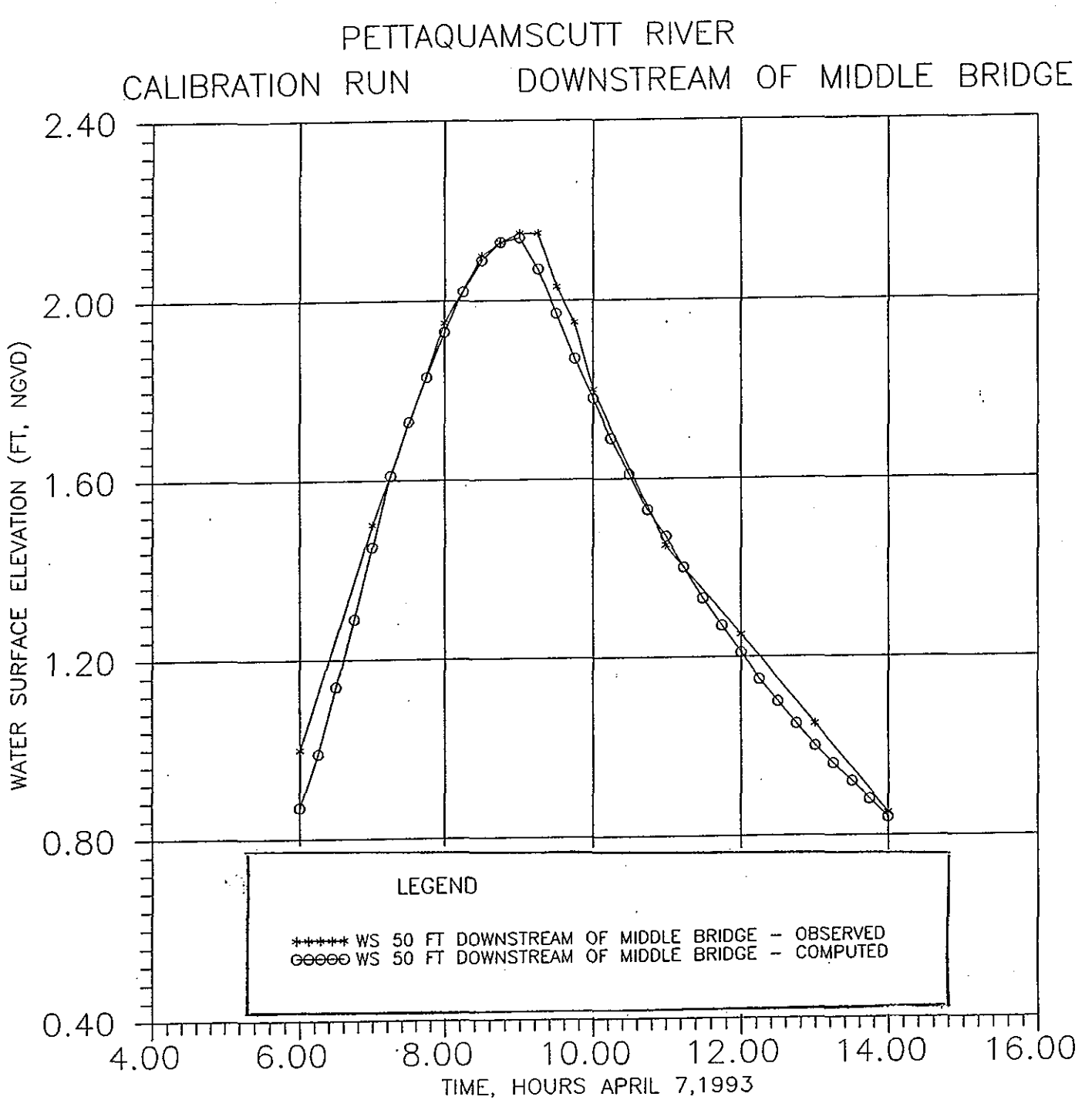

PETTAQUAMSCUTT RIVER
CALIBRATION RUN DOWNSTREAM OF MIDDLE BRIDGE
WATER SURFACE ELEVATION (FT, NGVD)
2.40
2.00
1.60
1.20
0.80
0.40
4.00
6.00
8.00
10.00
12.00
14.00
16.00
TIME, HOURS APRIL 7,1993
LEGEND
WS 50 FT DOWNSTREAM OF MIDDLE BRIDGE - OBSERVED
WS 50 FT DOWNSTREAM OF MIDDLE BRIDGE - COMPUTED

PLATE 11B

PETTAQUAMSCUTT RIVER

CALIBRATION RUN UPSTREAM OF MIDDLE BRIDGE

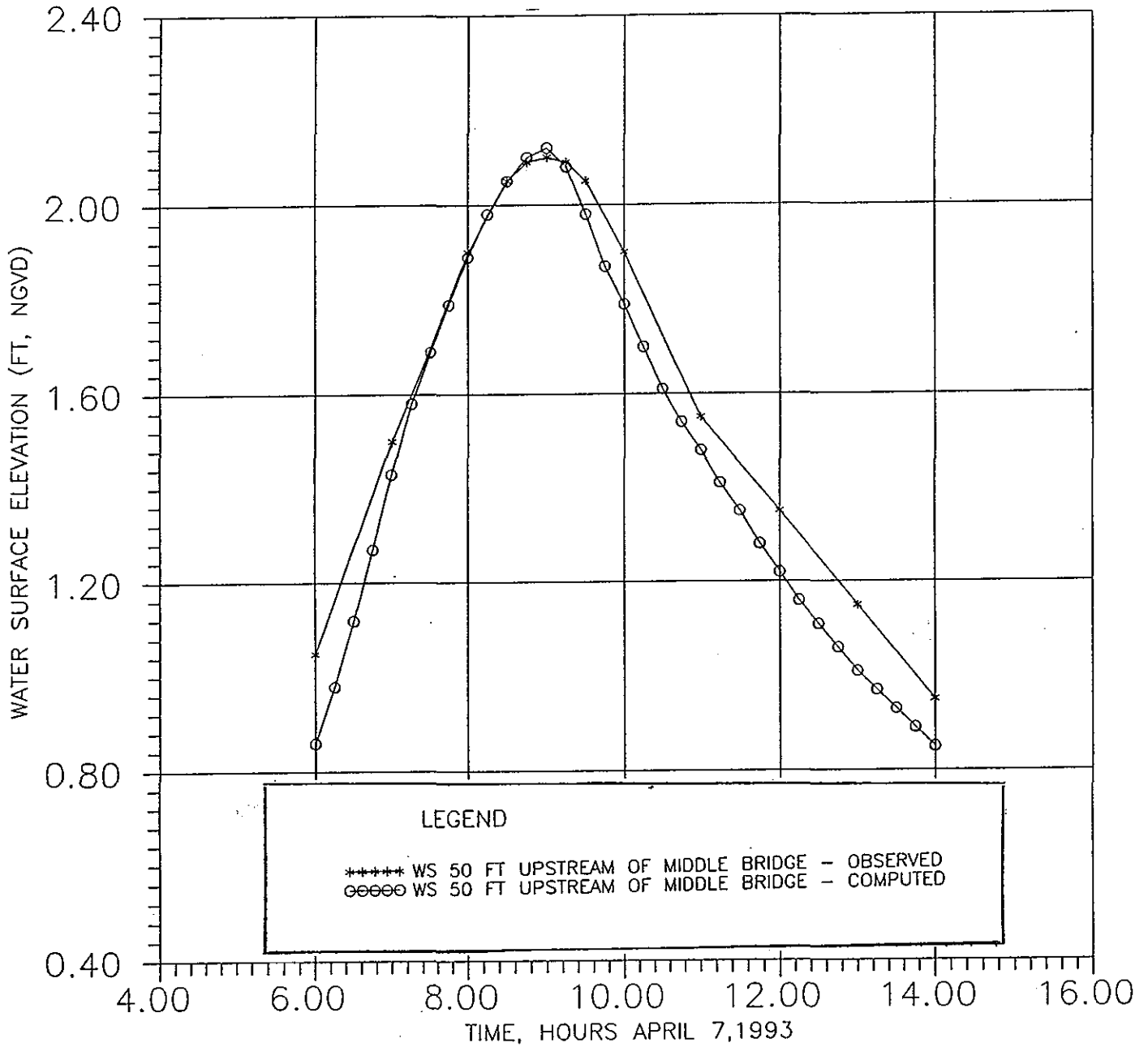


PLATE 12

PETTAQUAMSCUTT RIVER

VERIFICATION RUN DOWNSTREAM OF MIDDLE BRIDGE

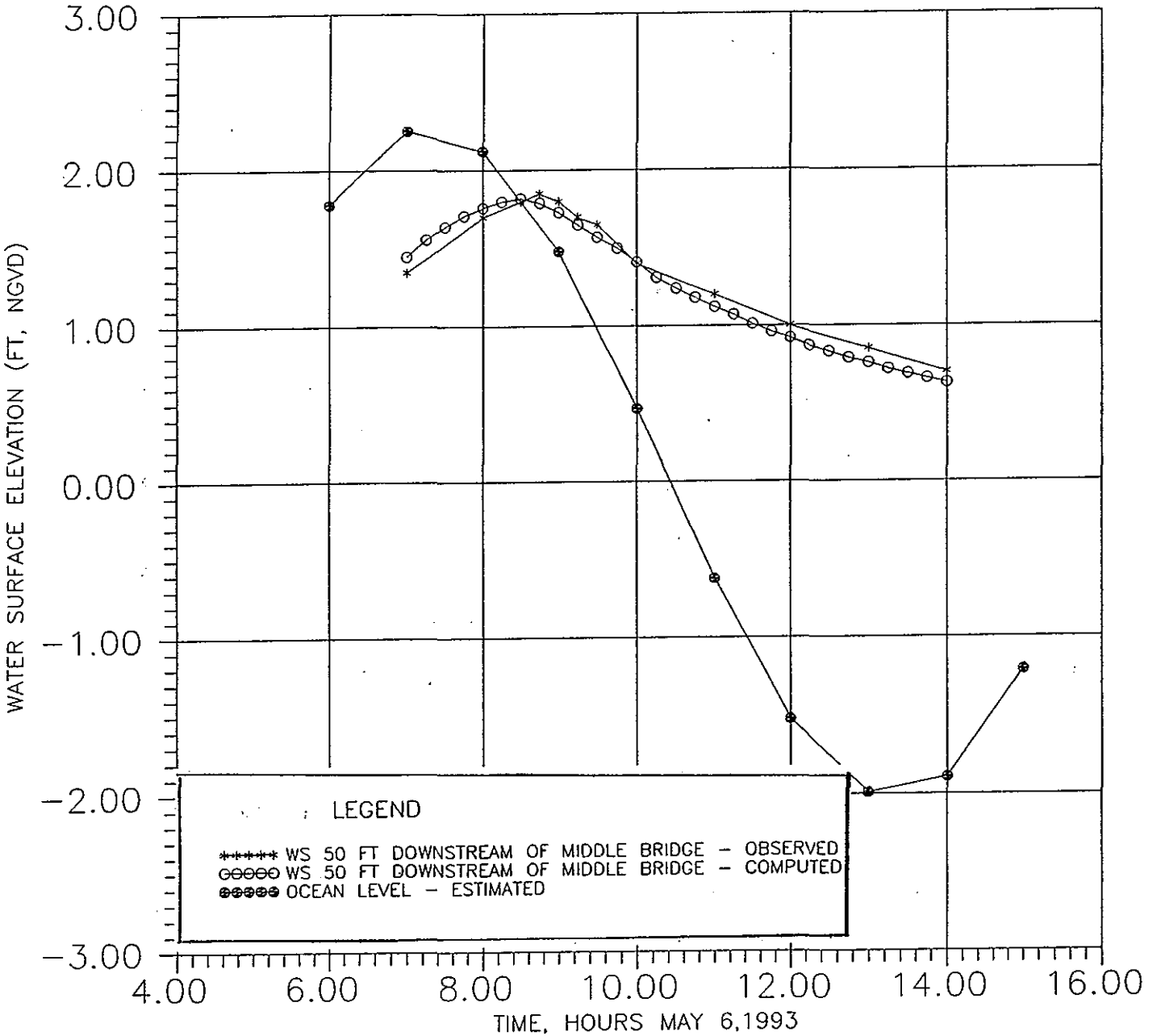


PLATE 13A

PETTAQUAMSCUTT RIVER

VERIFICATION RUN DOWNSTREAM OF MIDDLE BRIDGE

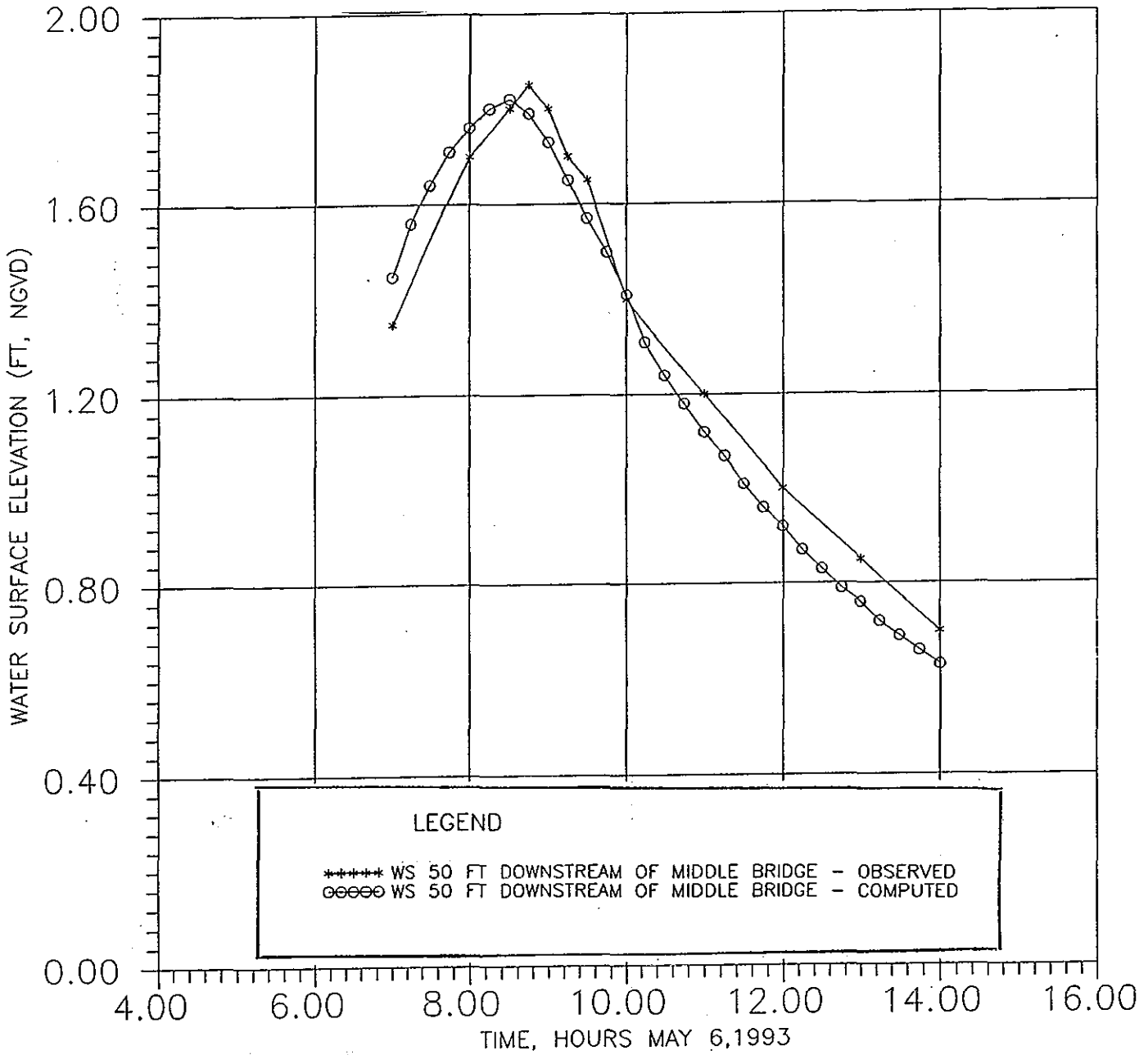


PLATE 13B

PETTAQUAMSCUTT RIVER

VERIFICATION RUN UPSTREAM OF MIDDLE BRIDGE

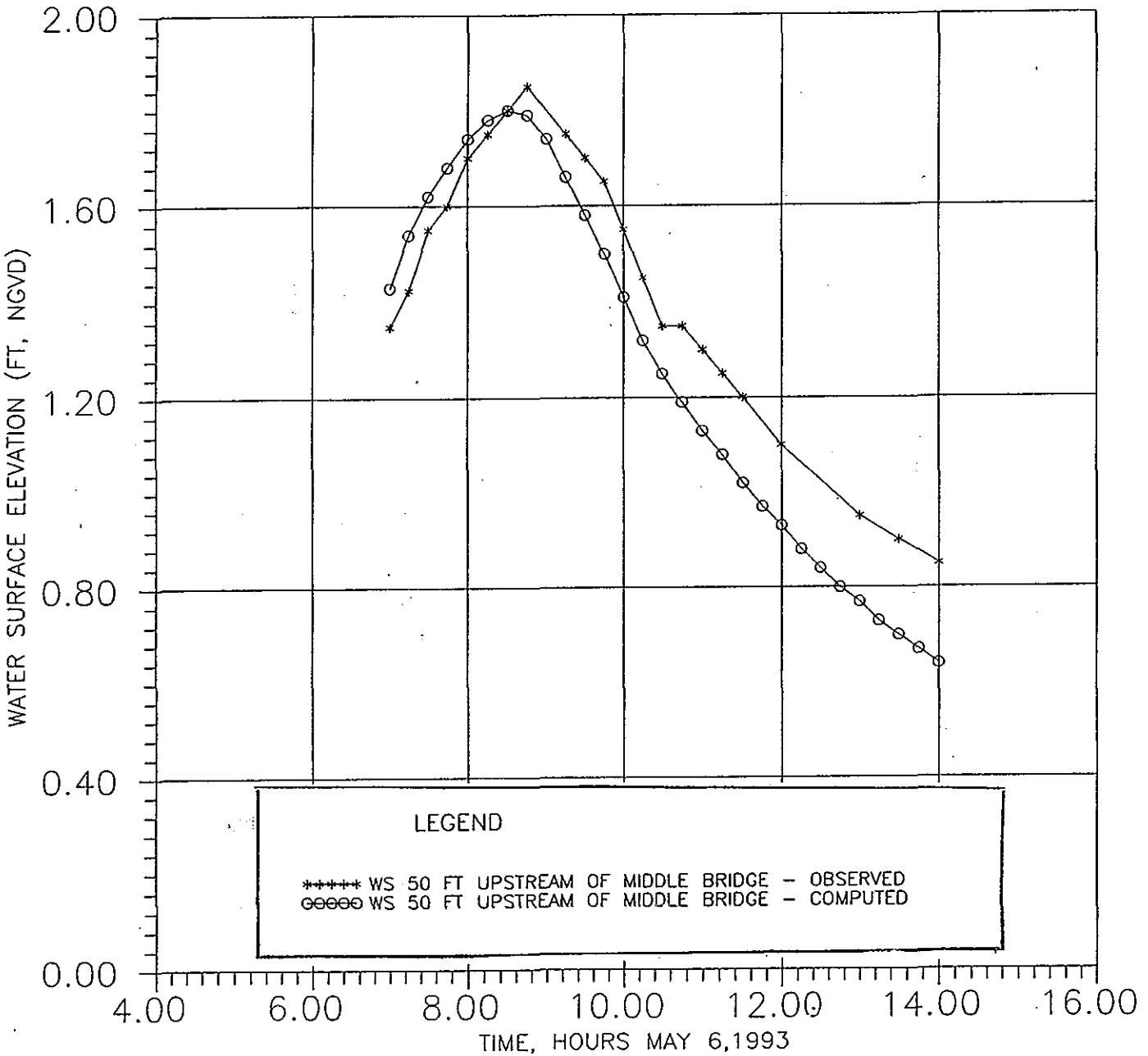


PLATE 14

PETTAQUAMSCUTT RIVER WATER SURFACE ELEVATIONS

UPSTREAM VS. DOWNSTREAM OF MIDDLE BRIDGE

APRIL 7, 1993 EVENT

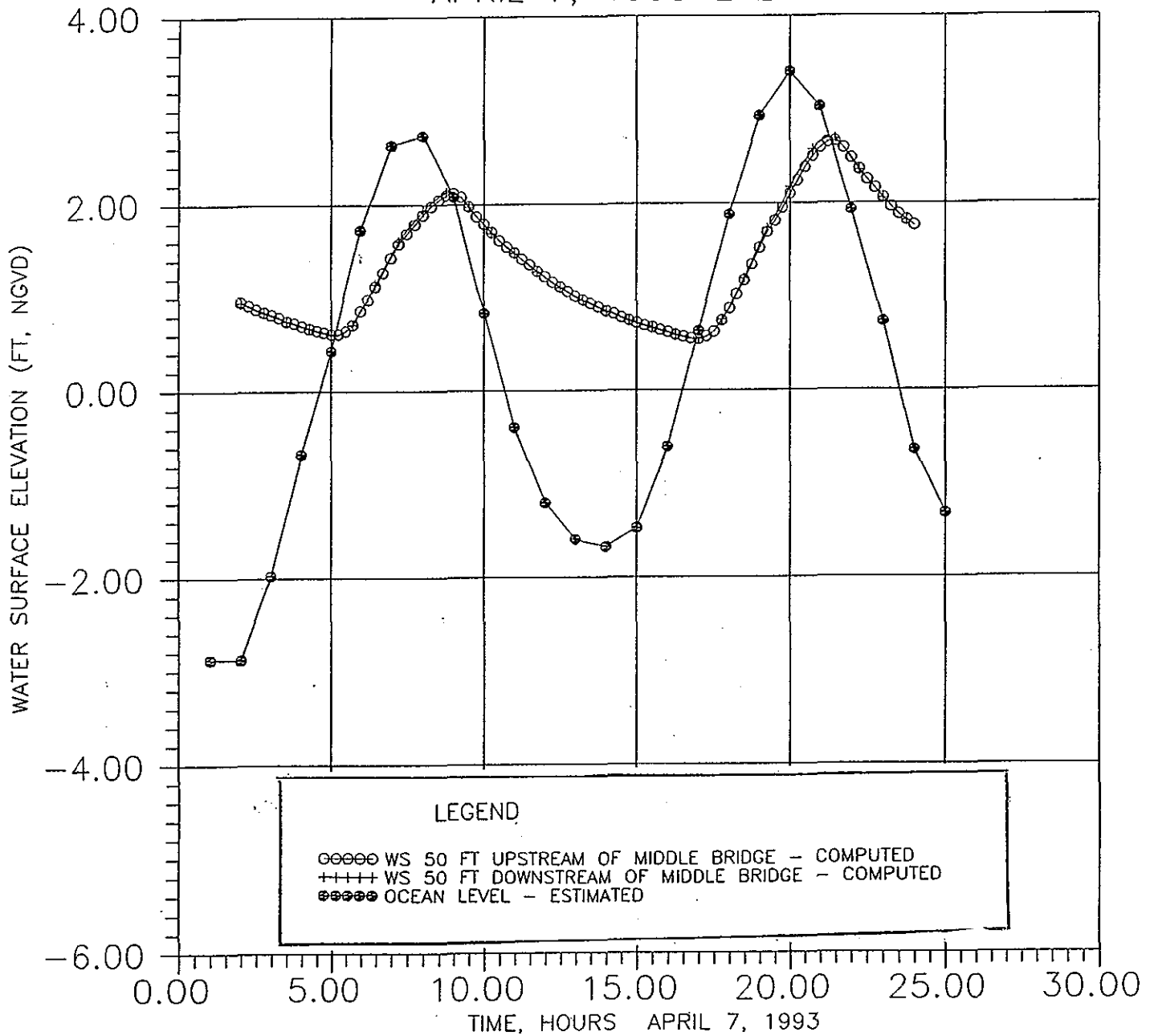


PLATE 15A

PETTAQUAMSCUTT RIVER WATER SURFACE ELEVATIONS

UPSTREAM VS. DOWNSTREAM OF MIDDLE BRIDGE

APRIL 7, 1993 EVENT

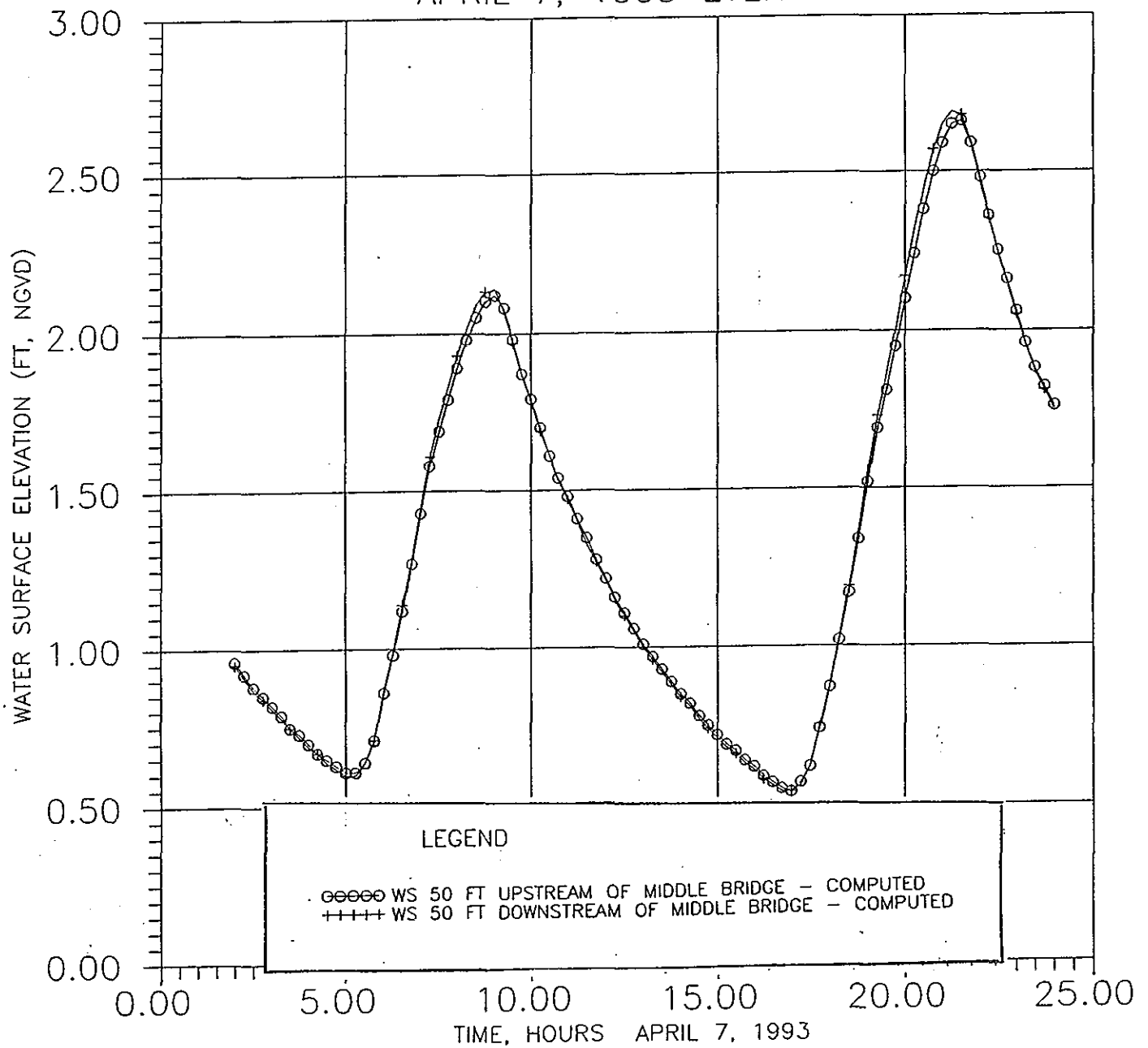


PLATE 15B

PETTAQUAMSCUTT RIVER WATER SURFACE ELEVATIONS

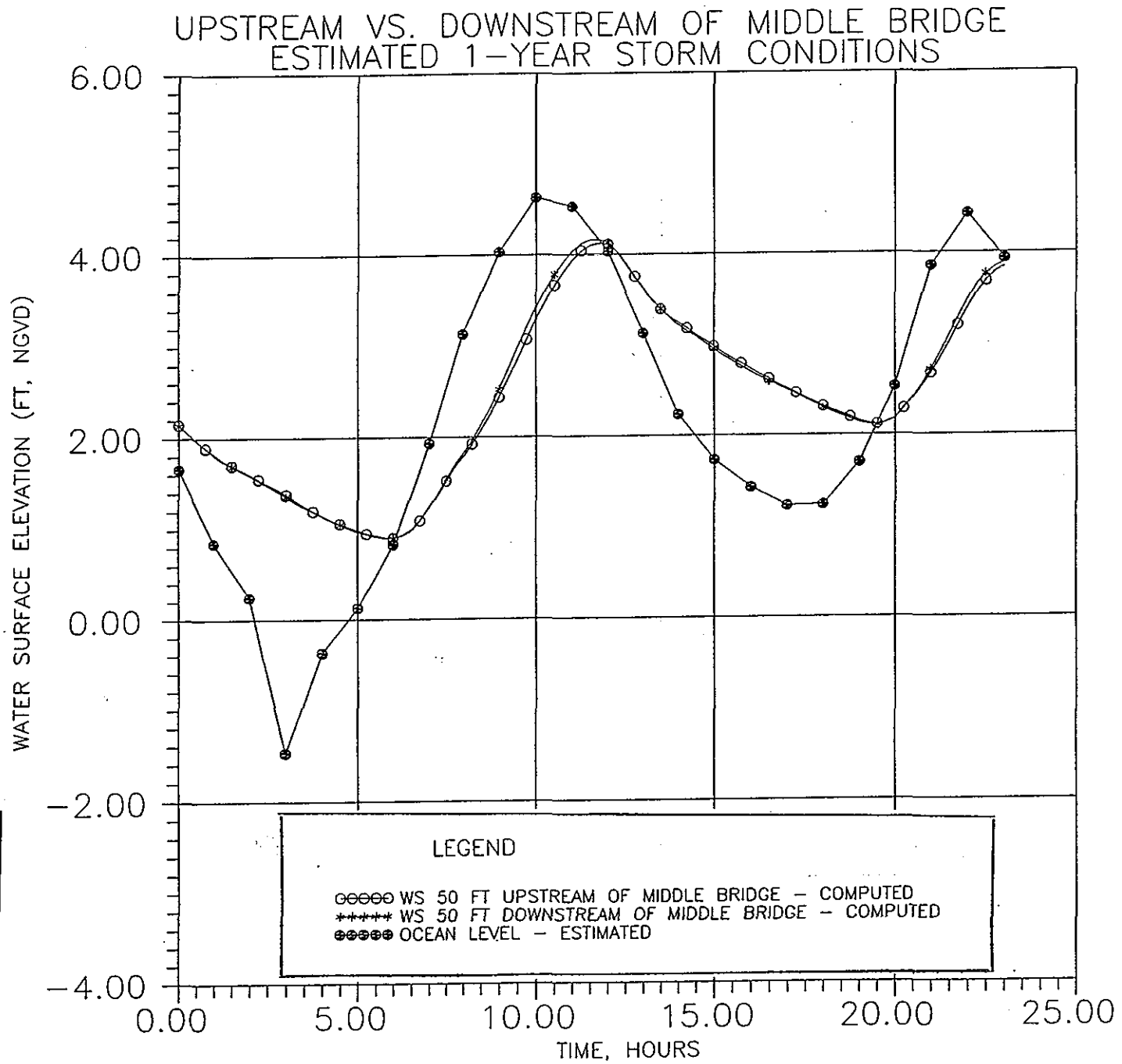


PLATE 16A

PETTAQUAMSCUTT RIVER WATER SURFACE ELEVATIONS

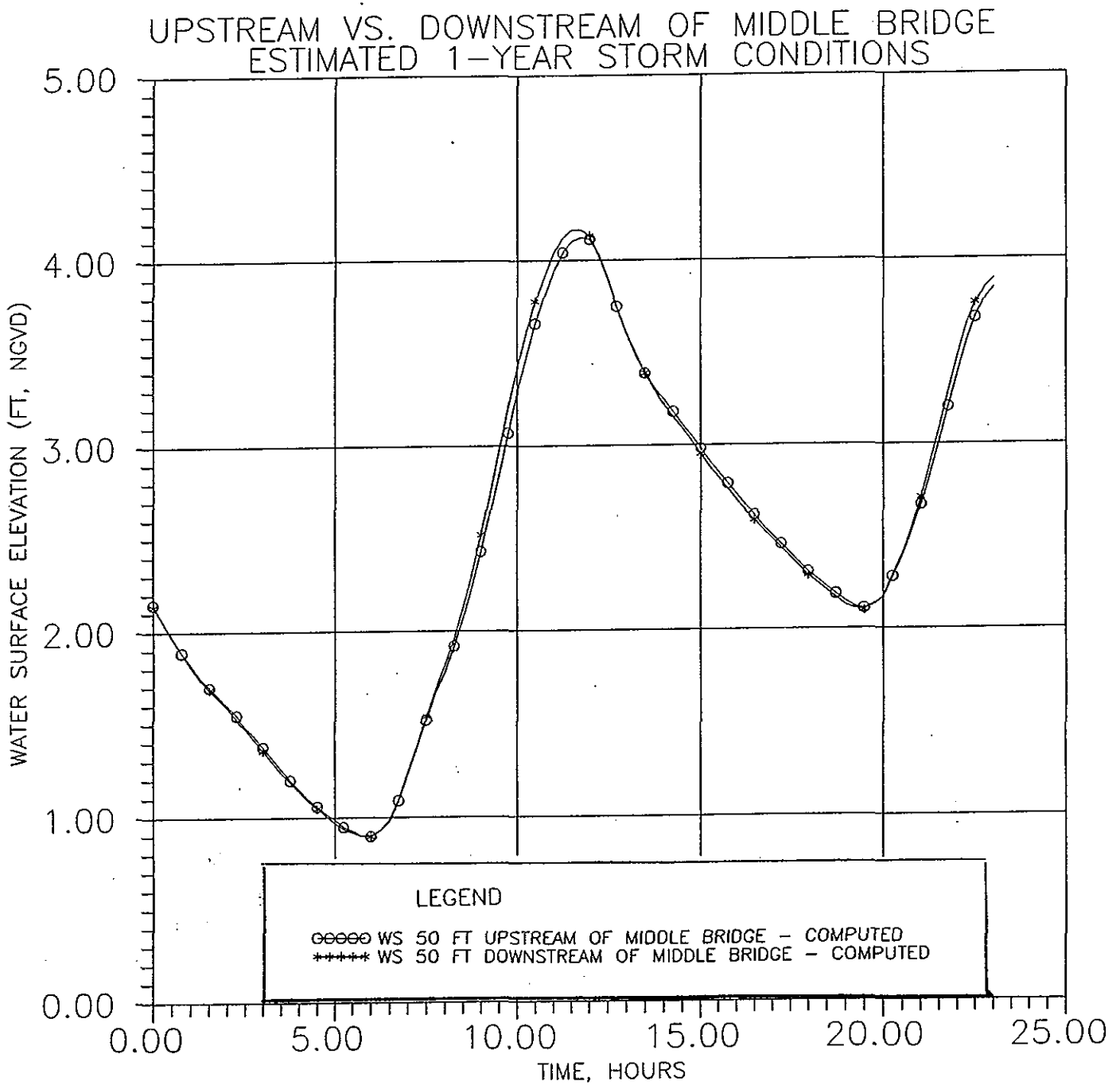


PLATE 16B

PETTAQUAMSCUTT RIVER WATER SURFACE ELEVATIONS

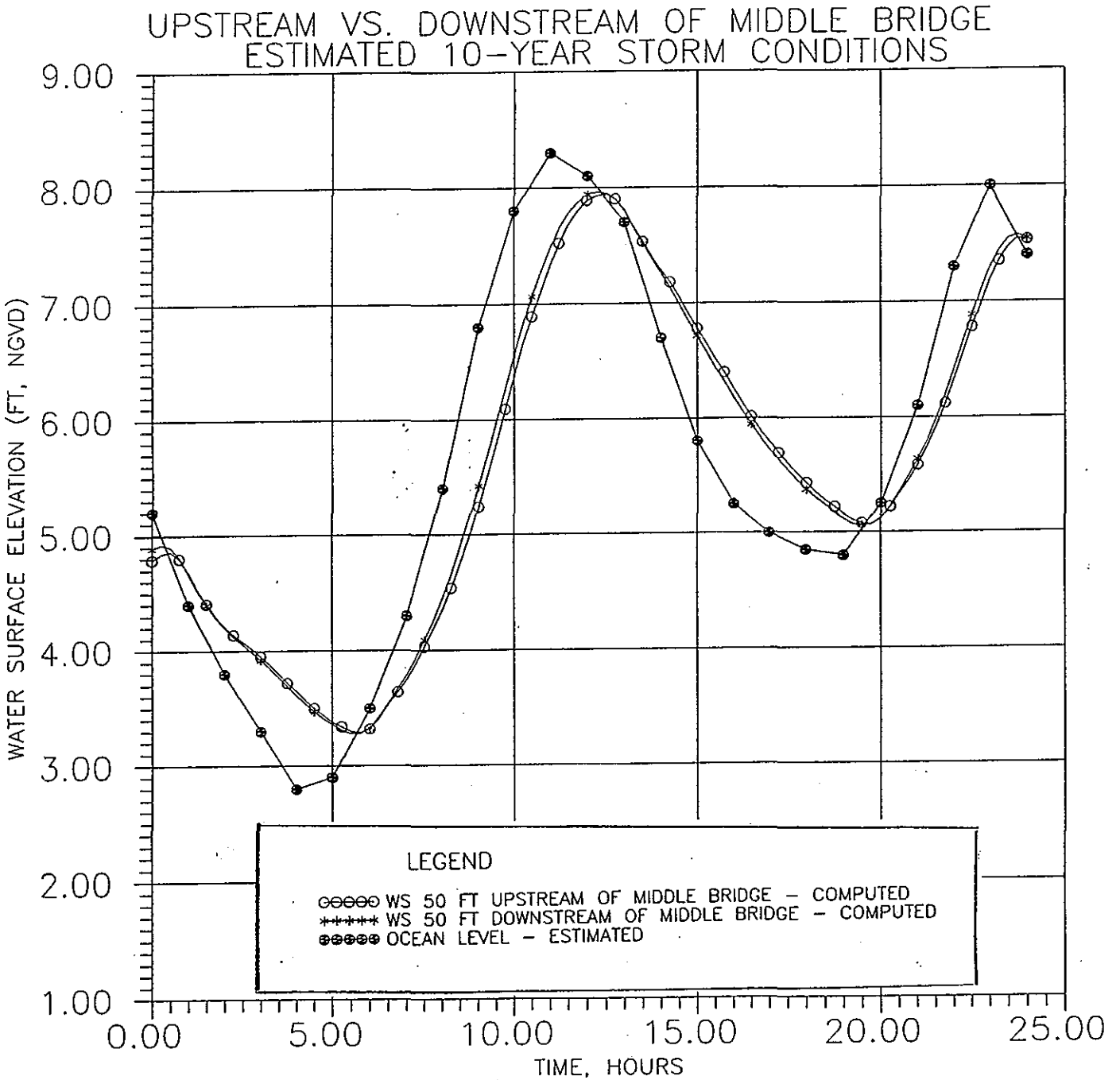


PLATE 17A

PETTAQUAMSCUTT RIVER WATER SURFACE ELEVATIONS

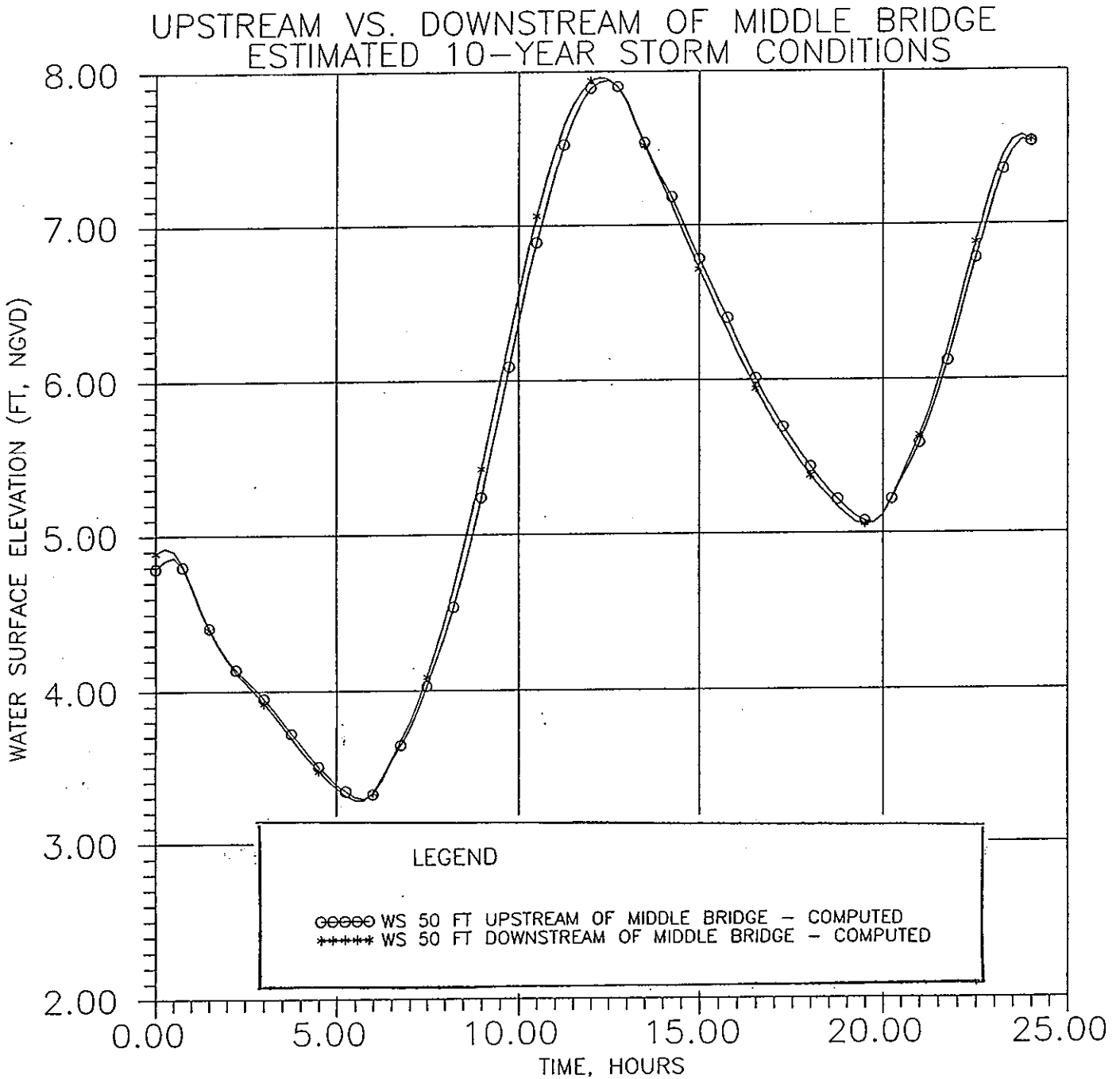


PLATE 17B

CROSS SECTIONS USED FOR BRIDGE ANALYSIS

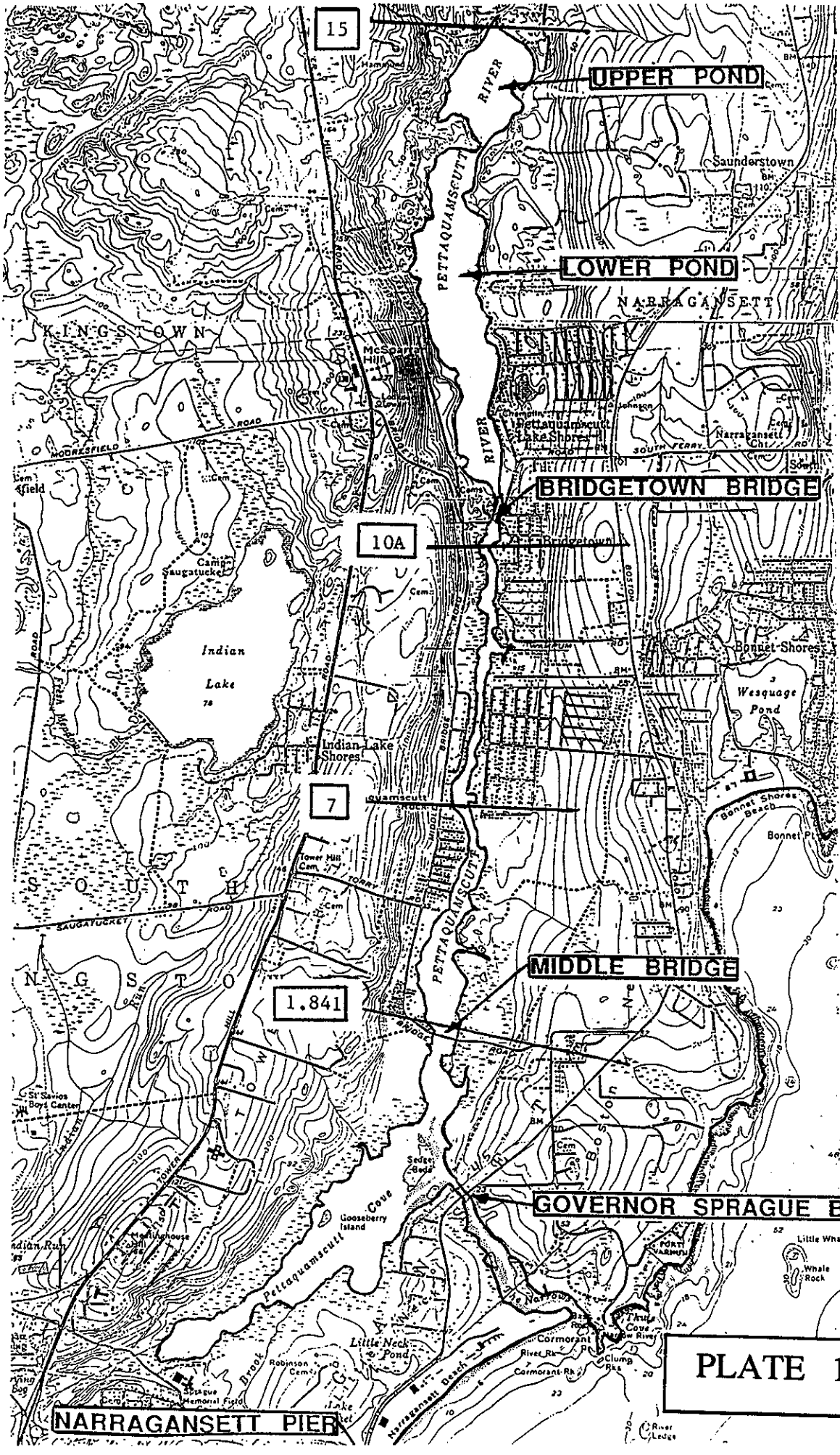
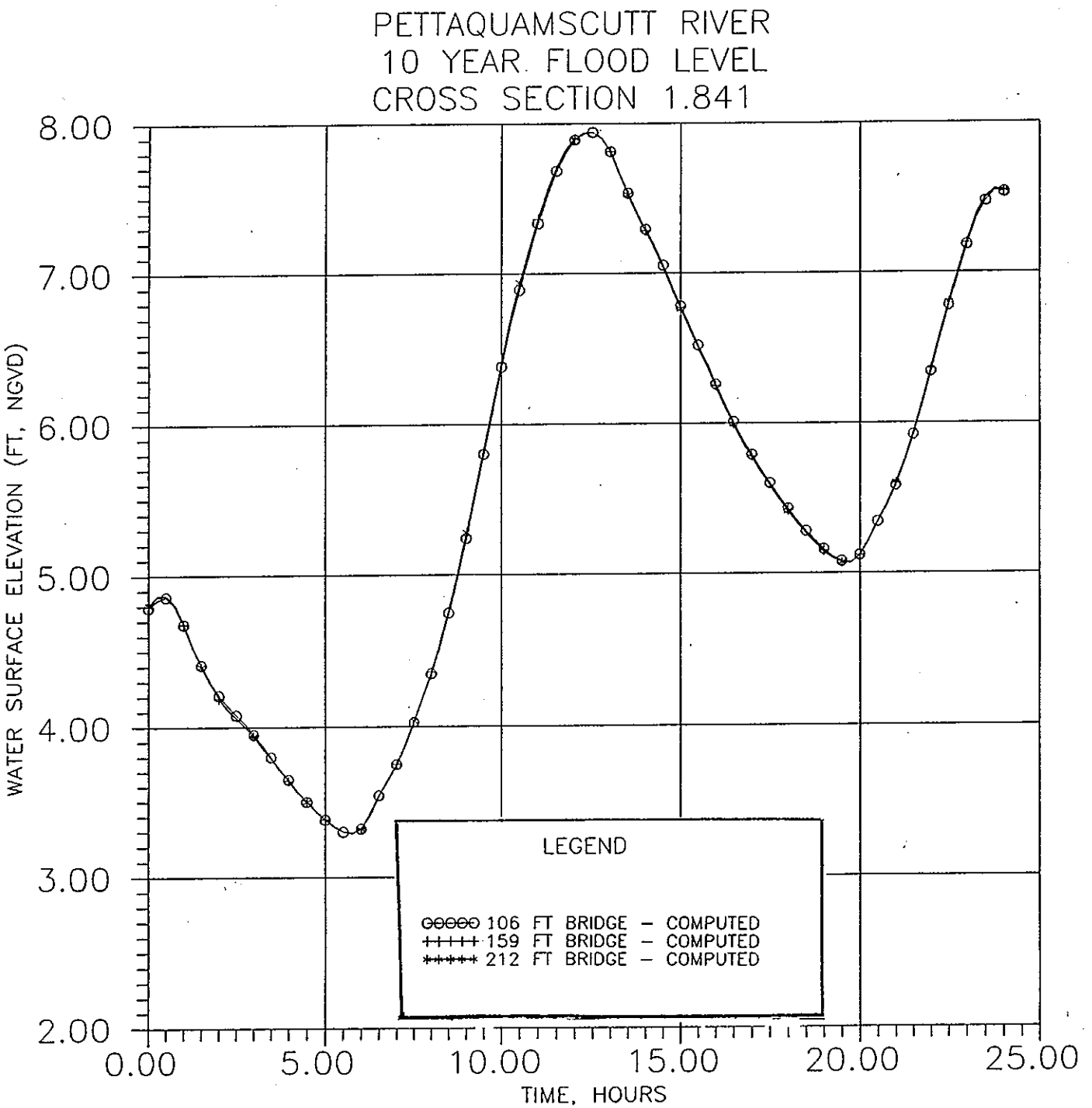


PLATE 19


PETTAQUAMSCUTT RIVER
10 YEAR FLOOD LEVEL
CROSS SECTION 1.841
WATER SURFACE ELEVATION (FT, NGVD)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
0.00
5.00
10.00
15.00
20.00
25.00
TIME, HOURS
LEGEND
106 FT BRIDGE - COMPUTED
159 FT BRIDGE - COMPUTED
212 FT BRIDGE - COMPUTED

PETTAQUAMSCUTT RIVER
10 YEAR FLOOD LEVEL

CROSS SECTION 7

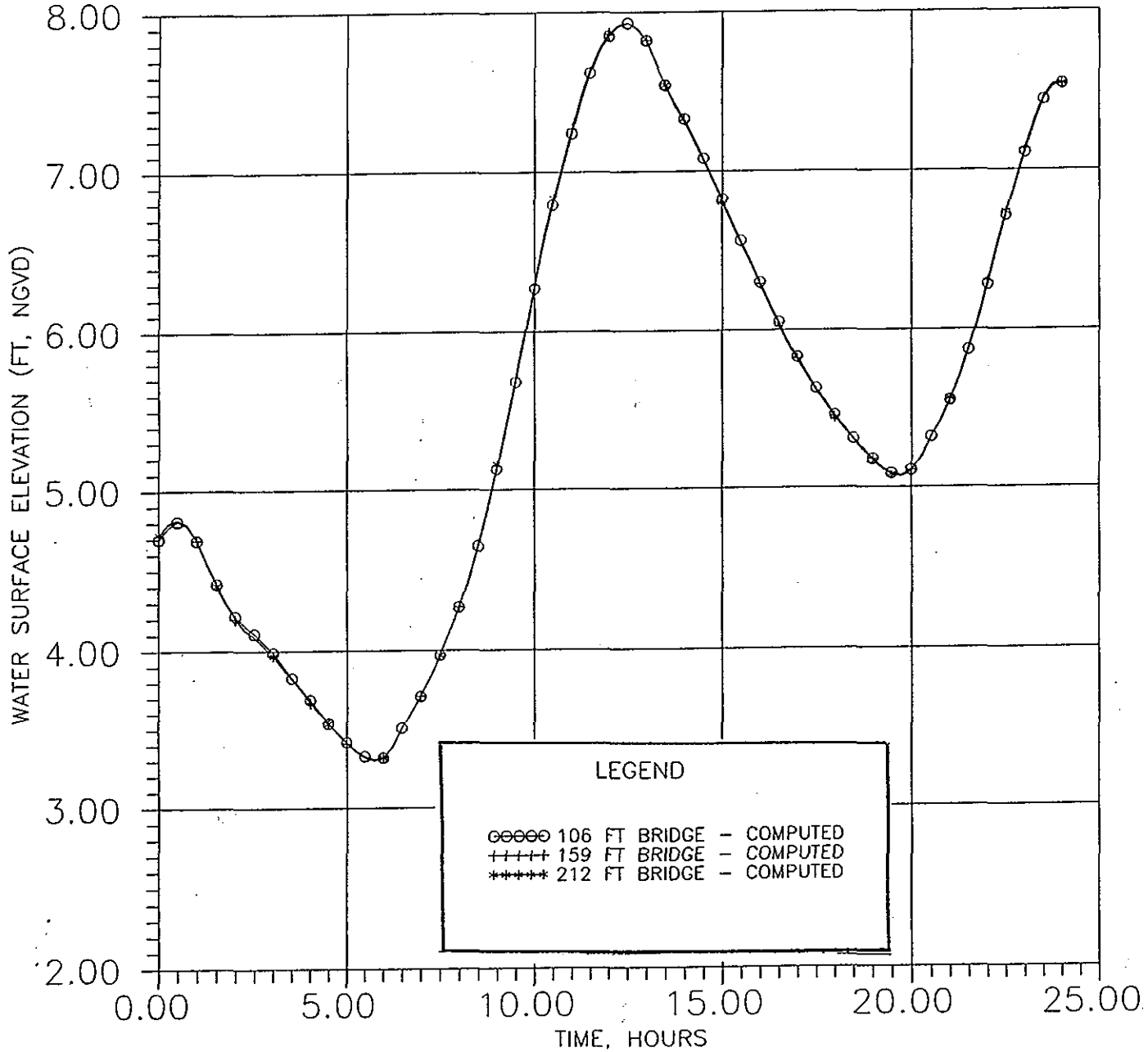


PLATE 20

PETTAQUAMSCUTT RIVER
10 YEAR FLOOD LEVEL

CROSS SECTION 10A

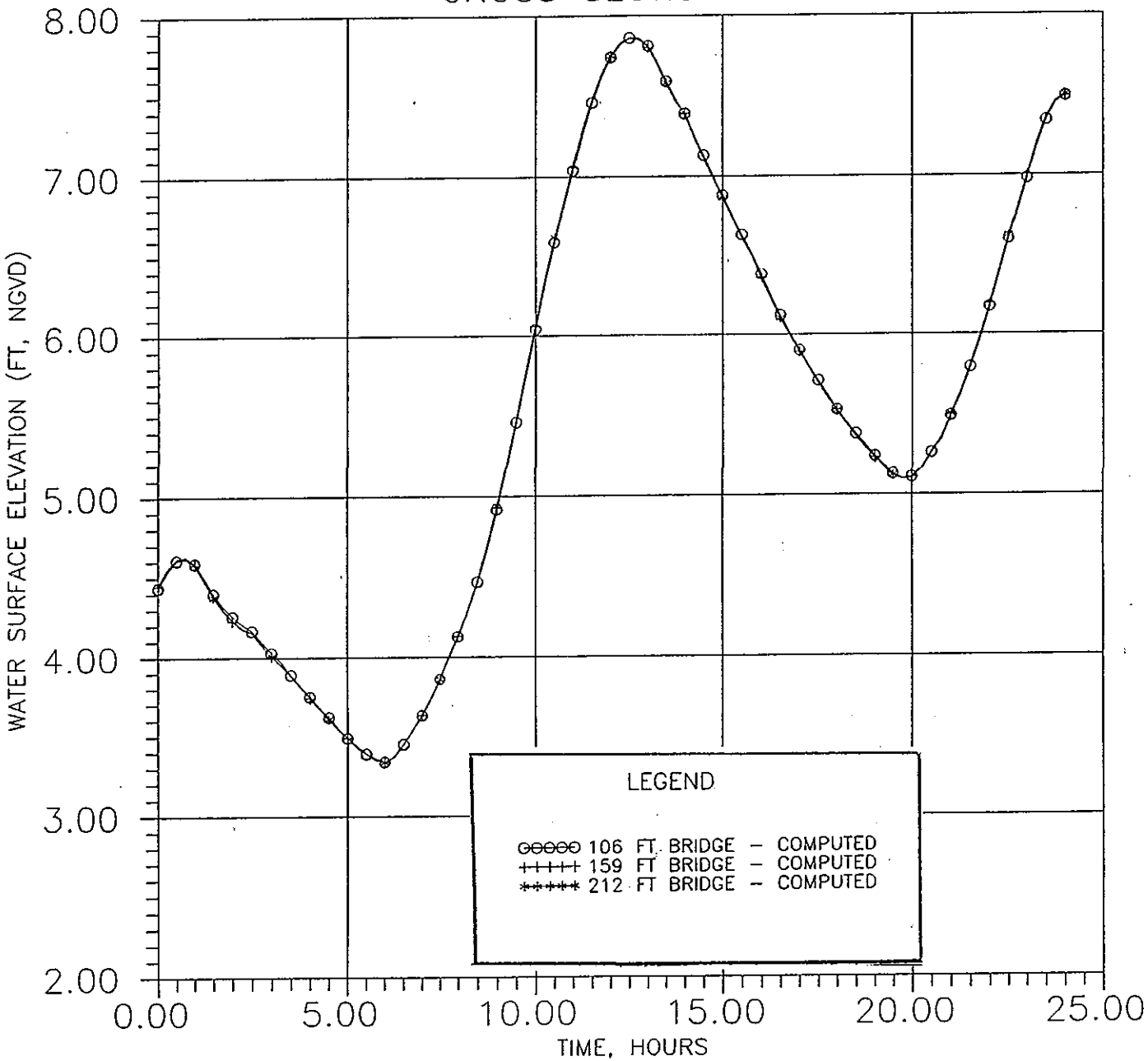


PLATE 21

PETTAQUAMSCUTT RIVER
10 YEAR FLOOD LEVEL

CROSS SECTION 15

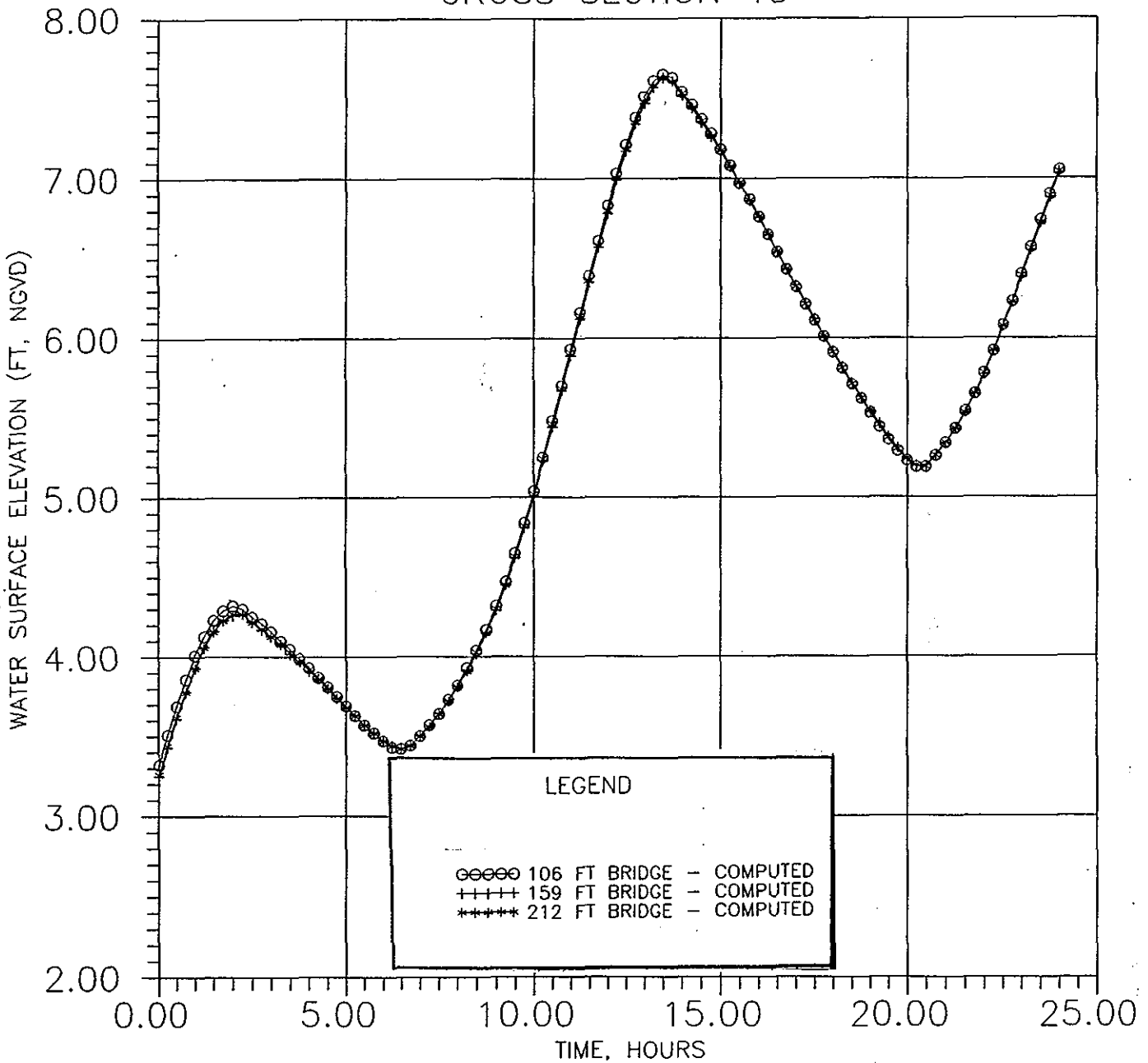


PLATE 22

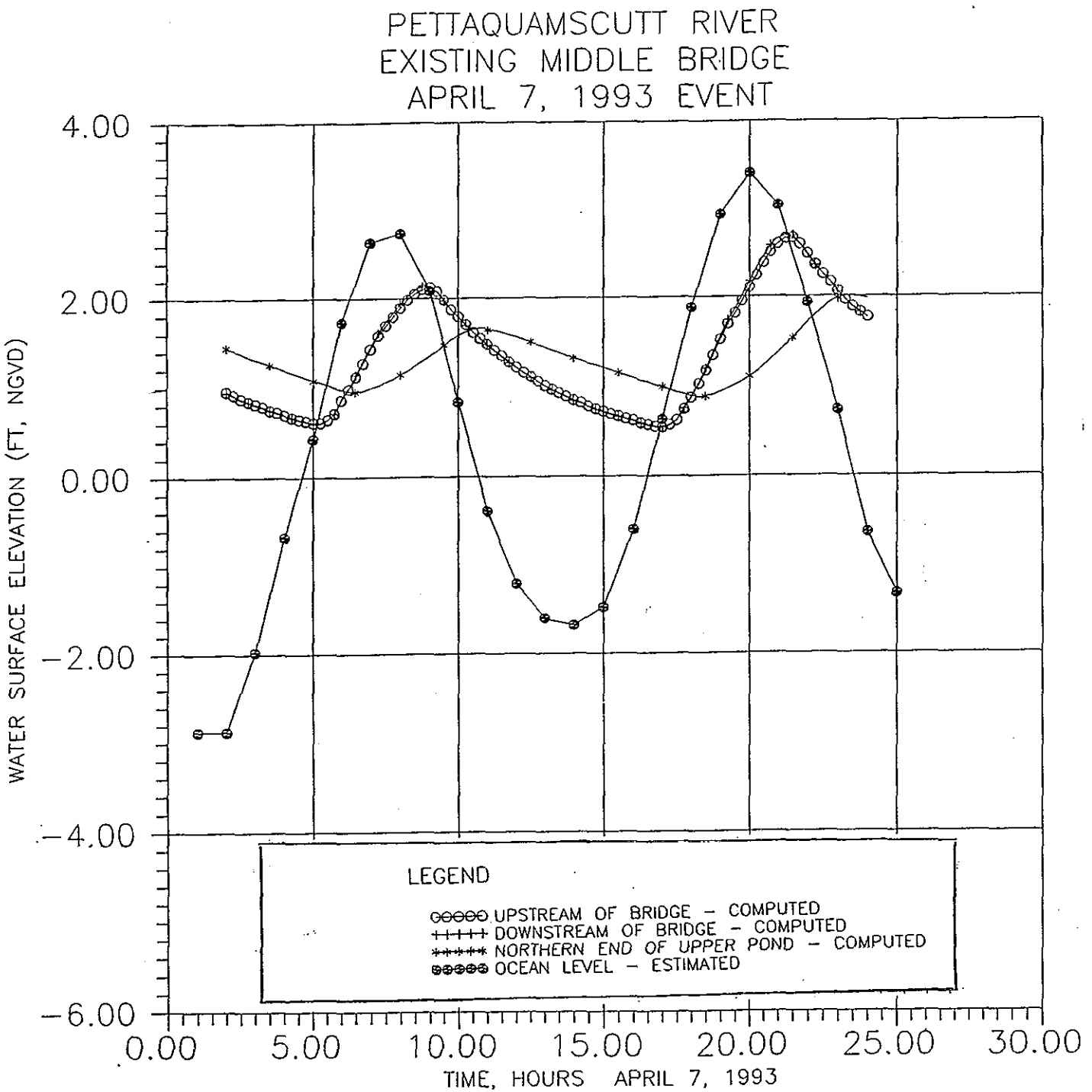

PETTAQUAMSCUTT RIVER
EXISTING MIDDLE BRIDGE
APRIL 7, 1993 EVENT
WATER SURFACE ELEVATION (FT, NGVD)
4.00
2.00
0.00
-2.00
-4.00
-6.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
TIME, HOURS APRIL 7, 1993
LEGEND
UPSTREAM OF BRIDGE - COMPUTED
DOWNSTREAM OF BRIDGE - COMPUTED
NORTHERN END OF UPPER POND - COMPUTED
OCEAN LEVEL - ESTIMATED

PLATE 23

PETTAQUAMSCUTT RIVER

COMPARISON OF W/S LEVELS FOR THREE ALTERNATIVE BRIDGE OPENINGS

CROSS SECTION 15

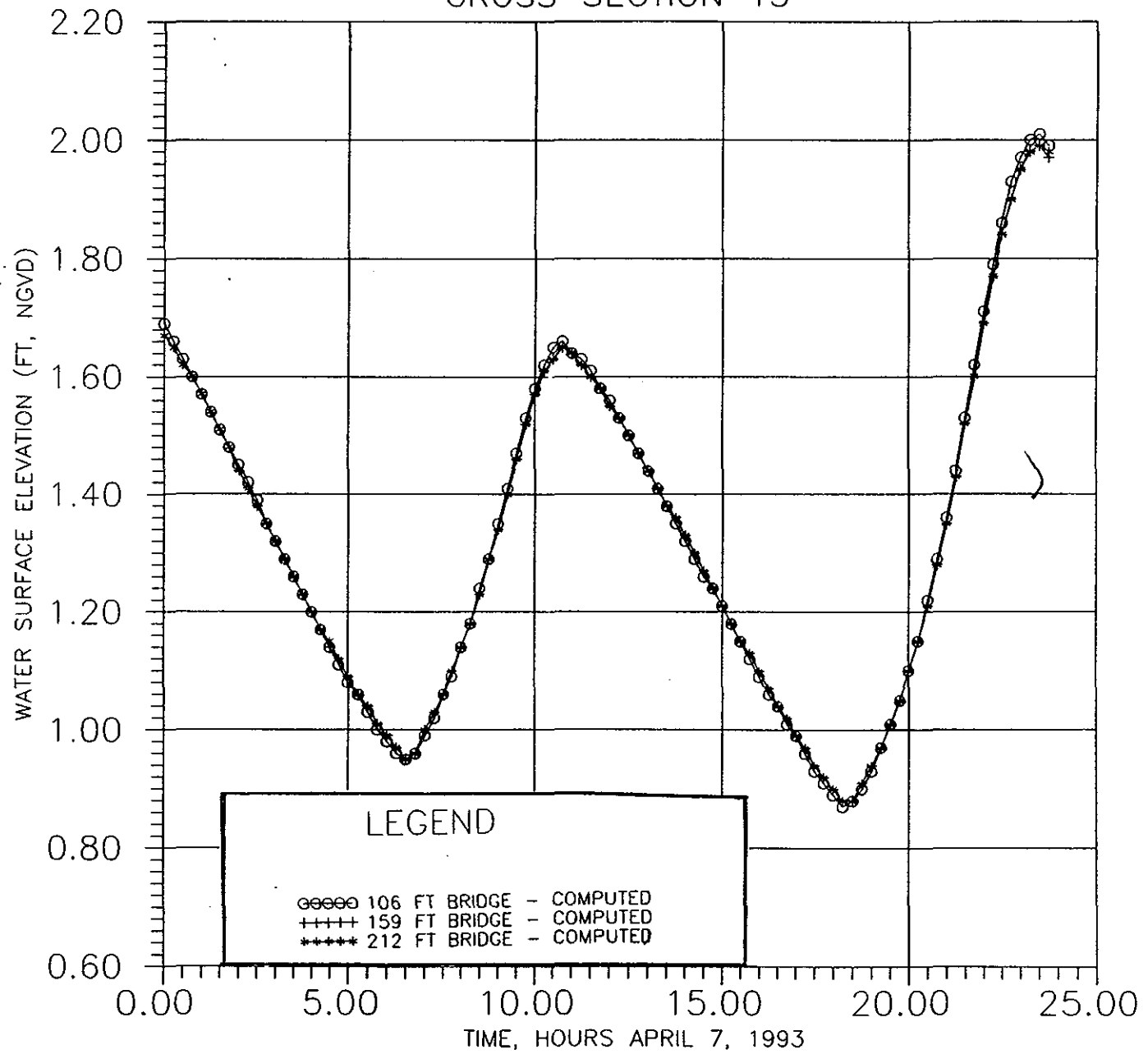


PLATE 24